PB-227 643

POTOMAC-PISCATAWAY DYE RELEASES AND WASTEWATER ASSIMILATION STUDIES

Norbert A. Jaworski, et al

Federal Water Pollution Control Administration
Annapolis, Maryland

December 1969

DISTRIBUTED BY:

NTIS

National Technical Information Service
U. S. DEPARTMENT OF COMMERCE
5285 Port Royal Road, Springfield Va. 22151

PB 227 643

Chesapeake Technical Support Laboratory
Middle Atlantic Region
Federal Water Pollution Control Administration
U. S. Department of the Interior

POTOMAC-PISCATAWAY
DYE RELEASES
AND
WASTEWATER ASSIMILATION STUDIES

Norbert A. Jaworski
and
James H. Johnson, Jr.

Technical Report No. 19
December 1969

Johan A. Aalto, Chief, CTSL

Field Survey Crew:

Robert L. Vallandingham
Alan Kirschbaum
Gerald Donovan

Reproduced by
NATIONAL TECHNICAL
INFORMATION SERVICE
U S Department of Commerce
Springfield VA 22151

TABLE OF CONTENTS

		Page
FOREWORD		iv
LIST OF FIGURES		v
LIST OF TABLES		viii
Chapter		
I	INTRODUCTION	I - 1
	A. Purpose and Scope	I - 1
	B. Authority	I - 2
	C. Acknowledgments	I - 3
II	SUMMARY AND CONCLUSIONS	II - 1
III	DESCRIPTION OF STUDY AREA	III - 1
IV	SURFACE DYE RELEASE NEAR PROPOSED POTOMAC OUTFALL LOCATION	IV - 1
	A. Release Conditions	IV - 1
	B. Transect Locations and Monitoring System	IV - 3
	1. Analytical Measurements	IV - 3
	2. Visual Monitoring	IV - 3
	C. Analysis of Dye Release Data	IV - 4
V	SUBSURFACE RELEASE NEAR PROPOSED POTOMAC OUTFALL LOCATION	V - 1
	A. Release Conditions	V - 1
	B. Transect Locations and Monitoring System	V - 1
	C. Analysis of Dye Release Data	V - 1
	1. Dye Intrusion	V - 1
	2. Time of Travel	V - 3
	3. Dispersion Coefficient	V -15

TABLE OF CONTENTS (Cont.)

Chapter		Page
VI	PISCATAWAY EMBAYMENT DYE RELEASE	VI - 1
	A. Release Conditions	VI - 1
	B. Transect Locations and Monitoring System	VI - 1
	C. Analysis of Dye Release Data	VI - 3
VII	ENGINEERING CONSIDERATIONS	VII - 1
	A. Dispersion	VII - 1
	B. Dilution and Transport	VII - 2
	C. Intrusion Into Embayments	VII - 13
	D. Time of Travel	VII - 14
	E. Discussion of Considerations	VII - 16
	APPENDIX	
	A. Mathematical Models	A - 1
	B. Determination of Dispersion Coefficient . . .	B - 1
	C. Piscataway Creek Survey	C - 1
	GLOSSARY	
	BIBLIOGRAPHY	

FOREWORD

The determination of the assimilation capacity of tidal waters receiving wastewater discharges is complicated not only by tidal excursion but by hydrographic features such as fresh water inflow that may affect mixing and dispersion. Dye studies, in conjunction with the use of mathematical models, are feasible means of investigating the effects of various parameters on water quality at both present and proposed outfall locations.

Previous studies have shown that nutrient intrusions into the lower portion of the Piscataway Embayment from the Potomac Estuary are far greater than the contribution from the Piscataway Wastewater Treatment Plant located in the upper portion of the embayment. However, it was not known what nutrient concentrations could be expected within the embayment under higher anticipated loading to the Piscataway plant if the outfall remained in the embayment.

A need existed for a study of the effects on water quality of alternative locations of the discharge from the Piscataway plant. While this report presents the results of dye and mathematical model simulation studies for the proposed Potomac Estuary and current outfall locations from the Piscataway Wastewater Treatment Plant, techniques and findings may give insight to other wastewater outfalls currently discharging into embayments of the Potomac Estuary.

LIST OF FIGURES

Number		Page
III- 1	Potomac Estuary Study Area	III- 4
III- 2	Potomac Estuary Chloride Concentration	III- 5
III- 3	Potomac Estuary near the Piscataway Embayment . . .	III- 7
IV- 1	Dye Release Sampling Stations - December 1968 . . .	IV- 2
IV- 2	Tidal Stages for Potomac near Piscataway December 10, 1968	IV- 6
IV- 3	Dye Position at 9:00 A.M. December 10, 1968 . . .	IV- 7
IV- 4	Dye Position at 10:00 A.M. December 10, 1968 . . .	IV- 8
IV- 5	Dye Position at 11:00 A.M. December 10, 1968 . . .	IV- 9
IV- 6	Dye Position at 1:00 P.M. December 10, 1968 . . .	IV-10
IV- 7	Dye Position at 3:00 P.M. December 10, 1968 . . .	IV-11
IV- 8	Dye Concentration Isopleth - December 12, 1968 . .	IV-12
V- 1	Dye Concentration Isopleth - April 26, 1969	V- 4
V- 2	Spacial Concentration of Dye - April 30, 1969 . . .	V- 5
V- 3	Spacial Concentration of Dye - May 2, 1969	V- 6
V- 4	Spacial Concentration of Dye - May 5, 1969	V- 7
V- 5	Spacial Concentration of Dye - May 5, 1969	V- 8
V- 6	Spacial Concentration of Dye - May 7, 1969	V- 9
V- 7	Spacial Concentration of Dye - May 10, 1969	V-10
V- 8	Spacial Concentration of Dye - May 13, 1969	V-11
V- 9	Spacial Concentration of Dye - May 14, 1969	V-12
V-10	Spacial Concentration of Dye - May 20, 1969	V-13
V-11	Spacial Concentration of Dye - May 26, 1969	V-14

LIST OF FIGURES (Continued)

Number		Page
V-12	Peak Concentration Movement Rate	V-16
V-13	Low Water Tidal Heights	V-17
V-14	Dispersion Coefficient vs Distance from Chain Bridge	V-20
VI- 1	Transect Locations - June 16, 1969	VI- 2
VI- 2	Dye Concentration Isopleth - June 18, 1969 . . .	VI- 4
VI- 3	Dye Concentration Isopleth - June 20, 1969 . . .	VI- 5
VI- 4	Dye Concentration Isopleth - June 23, 1969 . . .	VI- 6
VI- 5	Dye Concentration Isopleth - June 26, 1969 . . .	VI- 7
VII- 1	Simulated Pollutant Profiles - Potomac River Estuary	VII- 5
VII- 2	Piscataway Creek Surveys - TPO_4 as PO_4	VII- 6
VII- 3	Piscataway Creek Surveys - TKN as N	VII- 7
VII- 4	Piscataway Creek Surveys - Chlorophyll *a*	VII- 8
VII- 5	Piscataway Creek Surveys - DO	VII- 9
VII- 6	Simulated Pollutant Profiles - Piscataway Embayment	VII-10
VII- 7	Peak Movement for Varying Flows - Potomac Estuary	VII-15
A- 1	Interface Cross-sectional Area vs Distance . . .	A- 3
B- 1	Upper Potomac Estuary - April 30, 1969	B- 2
B- 2	Upper Potomac Estuary - May 2, 1969	B- 4
B- 3	Upper Potomac Estuary - May 5, 1969	B- 6
B- 4	Upper Potomac Estuary - May 5, 1969	B- 8

LIST OF FIGURES (Continued)

Number		Page
B- 5	Upper Potomac Estuary - May 7, 1969	B-10
B- 6	Upper Potomac Estuary - May 10, 1969	B-12
B- 7	Upper Potomac Estuary - May 13, 1969	B-14
B- 8	Upper Potomac Estuary - May 14, 1969	B-16
B- 9	Upper Potomac Estuary - May 20, 1969	B-18
B-10	Upper Potomac Estuary - May 26, 1969	B-20
B-11	Piscataway Creek - June 20, 1969	B-22
B-12	Piscataway Creek - June 23, 1969	B-24

LIST OF TABLES

Number		Page
III- 1	Wastewater Loadings - Potomac Estuary Intensive Survey, August 11-18, 1969	III- 2
V- 1	Potomac Estuary Sampling Stations	V- 2
V- 2	Dispersion Coefficient Summary - Potomac Estuary	V-19
VII- 1	Potomac Estuary Physical Parameters	VII- 3
VII- 2	Nutrient Loadings - Piscataway Wastewater Treatment Facility	VII-12
B- 1	Potomac Estuary Dye Analysis - April 30, 1969 . .	B- 3
B- 2	Potomac Estuary Dye Analysis - May 2, 1969 . . .	B- 5
B- 3	Potomac Estuary Dye Analysis - May 5, 1969 . . .	B- 7
B- 4	Potomac Estuary Dye Analysis - May 5, 1969 . . .	B- 9
B- 5	Potomac Estuary Dye Analysis - May 7, 1969 . . .	B-11
B- 6	Potomac Estuary Dye Analysis - May 10, 1969 . . .	B-13
B- 7	Potomac Estuary Dye Analysis - May 13, 1969 . . .	B-15
B- 8	Potomac Estuary Dye Analysis - May 14, 1969 . . .	B-17
B- 9	Potomac Estuary Dye Analysis - May 20, 1969 . . .	B-19
B-10	Potomac Estuary Dye Analysis - May 26, 1969 . . .	B-21
B-11	Piscataway Creek Dye Analysis - June 20, 1969 . .	B-23
B-12	Piscataway Creek Dye Analysis - June 23, 1969 . .	B-25

LIST OF TABLES (Continued)

Number		Page
C- 1	Piscataway Creek Survey - 1968	C- 1
C- 2	Piscataway Creek Survey - April 30-May 1, 1969 . .	C- 4
C- 3	Piscataway Creek Survey - May 13, 1969	C- 5
C- 4	Piscataway Creek Survey - June 23, 1969	C- 6
C- 5	Piscataway Creek Survey - July 15, 1969	C- 7
C- 6	Piscataway Creek Survey - August 5, 1969	C- 8
C- 7	Piscataway Creek Survey - December 8, 1969	C- 9

CHAPTER I

INTRODUCTION

A. PURPOSE AND SCOPE

As part of the Chesapeake Bay-Susquehanna River Basins Project, the Chesapeake Technical Support Laboratory (CTSL)* of the Middle Atlantic Region, Federal Water Pollution Control Administration (FWPCA) has undertaken an extensive water quality management study of the Potomac River Basin. A significant part of this study has been to determine the effect of organic matter including nutrients on the water quality in the upper Potomac Estuary.

In the early summer of 1968, there was considerable public interest in the operation of the new Piscataway Wastewater Treatment Plant (PWTP) and the effect of the highly-treated plant effluent on water quality in the Piscataway embayment. An investigation was made and a report prepared by CTSL on operation of the plant and effect on water quality conditions in the Piscataway embayment [1].

One of the recommendations in the report was the extension of the outfall to the main channel of the Potomac Estuary as originally proposed by the Washington Suburban Sanitary Commission (WSSC). To assist in the engineering analysis, dye releases were made in the vicinity of the proposed outfall point and in the embayment to

* Formerly Chesapeake Field Station

aid in determining the following:

1. The amount of possible direct intrusion of treated effluent into the embayment during the first flood tide,

2. The transport of wastewater constituents into and out of the Piscataway embayment from the Potomac Estuary during tidal flushing,

3. The possible use of aerial photography as a means of supplementing fluorometric dye studies,

4. A comparison of the dispersion capacity of the Piscataway embayment and the Potomac Estuary by use of a "dispersion coefficient," and

5. The verification of the previously determined dispersion coefficients required in the use of mathematical models of the Potomac Estuary.

This study was limited to diffusion, dispersion, and dilution effects of the receiving water. Studies are currently being made by CTSL on specific wastewater treatment requirements by zones and nutrient transport mechanisms required to investigate and develop alternative water management plans for the upper estuary.

B. AUTHORITY

This report is prepared under the provisions of the Federal Water Pollution Control Act as amended (33 U.S.C. 466 et seq.) which directed the Secretary of the Interior to develop programs for eliminating pollution of interstate waters in cooperation with other federal agencies, state water pollution control

agencies, and the municipalities and industries involved.

C. ACKNOWLEDGMENTS

The assistance and cooperation of the following agencies is gratefully acknowledged:

Washington Suburban Sanitary Commission
Maryland State Department of Health
Maryland Department of Water Resources
Maryland Department of Chesapeake Bay Affairs
NFIC, FWPCA, Cincinnati, Ohio

Their contributions enabled CTSL to collect, assemble, and evaluate the necessary data in a much shorter time period than would otherwise have been required. Special acknowledgment is made for the aerial photography provided by C. L. Robey of the Division of Marine Police, Maryland Department of Chesapeake Bay Affairs.

CHAPTER II

SUMMARY AND CONCLUSIONS

Two dye releases were made in the main channel of the Potomac Estuary to simulate the movement of the effluent from the proposed outfall of the Piscataway Wastewater Treatment Plant. A third release was made in the upper portion of the Piscataway embayment to study movement of an effluent discharged in that area. Based on the data from the releases and the results from numerous simulations by mathematical models of the upper estuary, and of the Piscataway embayment, the following summary and conclusions were prepared:

1. Results of the first study in which dye was released at the surface indicated that direct intrusion into the embayment (on the first tidal cycle with no mixing) would occur if the Piscataway Wastewater Treatment Plant (PWTP) outfall were placed at a 20 foot depth at the proposed location.

2. No direct intrusion was observed during the second dye release which was made at the same general location but at a depth of 40 feet. After two tidal cycles, intrusion of dye into the embayment was confirmed. The intrusion was by a well-mixed dye, similar in concentration to that in the Potomac, and not by a "slug" as occurred during the first flood tide after surface release.

3. The average time of travel of the peak dye concentration, although greatly affected by wind conditions, showed good agreement with values calculated by the Potomac Estuary mathematical model.

4. The dye release in the upper Piscataway embayment, in which there is very little fresh water flow, indicated that movement of the dye is caused mainly by tidal dispersion. Approximately three weeks were required for the dye to diffuse out of the embayment.

5. Dispersion coefficients determined from data from the subsurface Potomac dye release were consistent with values previously calculated from an earlier dye study and from salinity intrusion data.

6. The dispersion coefficients in the Potomac Estuary near Washington, D. C. are about 0.05 square miles per day (smpd) and increase downstream as a function of the cross-sectional area with a maximum value of 10.0 smpd near the Chesapeake Bay.

7. The dispersion coefficient is about 0.66 smpd in the Potomac Estuary near the Piscataway embayment and about 0.05 smpd in the embayment.

8. Visual observation of the dye as well as use of aerial photography were most helpful during the initial days. Visible movement can be detected over large areas in a relatively short time.

9. The results of these investigations indicated that the following should be considered in locating any outfall in the upper Potomac Estuary:

a. Relative locations of existing and proposed wastewater outfalls,

b. Dispersion characteristics of the receiving water,

c. Effects of dilution and transport as influenced by cross-sectional areas and tidal exchange, and

d. Protection of high water quality use areas such as shellfish beds.

10. Mathematical model simulations indicate that the Potomac Estuary near the proposed outfall has about a hundred-fold greater capacity to receive and transport a pollutant than does the Piscataway embayment.

11. Based on the dye release, water quality surveys and mathematical simulations, the most advantageous wastewater discharge locations (in terms of a predicted response to a given pound loading of waste) appears to be the main channel of the Potomac Estuary and not in embayments with relatively small fresh water inflow rates such as the Piscataway embayment.

12. In order to maintain the same increase in nutrient levels in the Piscataway embayment as used in developing the removal requirements for the main stem of the Potomac Estuary, the maximum loadings of phosphorus and nitrogen were determined to be 50 and 250 lbs/day, respectively.

13. With the proposed expansion of the Piscataway Waste Treatment Plant capacity to 15 mgd, the removal requirements for phosphorus and nitrogen as recommended by the conferees in the recent Potomac Enforcement Conference will result in nutrient concentrations in the upper Piscataway embayment similar to those in the main channel of the Potomac Estuary.

14. Any significant expansion over the 15 mgd system will require nutrient removal above that recommended by the Enforcement Conference.

CHAPTER III

DESCRIPTION OF STUDY AREA

The Potomac River Basin is the second largest watershed in the Middle Atlantic States. Its tidal portion begins at Little Falls in the Washington, D. C. metropolitan area and extends 116 miles southeastward to the Chesapeake Bay. (Figure III-1)

The estuary is several hundred feet in width at its head near Washington and broadens to nearly six miles at its mouth. A shipping channel with a minimum depth of 24 feet is maintained in the estuary up to Washington. Except for the channel and a small reach just below Chain Bridge where depths up to 80 feet are found, the estuary is relatively shallow with an average cross-sectional depth usually less than 15 feet.

The upper tidal portion of the estuary from Marshall Hall at River Mile 21.5 to Washington contains fresh water. In the middle portion of the estuary from Marshall Hall to Indian Head at River Mile 29.5, there is a transition zone from fresh water to brackish water. The upper boundary of the salt wedge varies with fresh water in flow and tidal stage. Figure III-2 exhibits the intrusion of salt from the Chesapeake Bay measured during an intensive survey in September, 1966 when the fresh water flow was about 780 cfs.

The effluent from 12 wastewater treatment plants, serving a population of about 2,500,000 people, is discharged into the upper estuary. (Table III-1)

TABLE III-1
BOD, TOC, AND S.SOLIDS
WASTEWATER LOADINGS
Potomac Estuary Intensive Survey
August 11-18, 1969

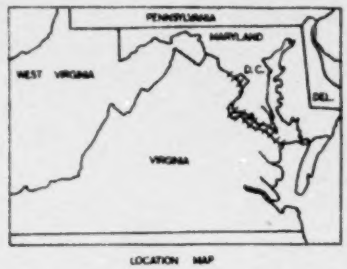
Facility	Pop. Served	Flow (mgd)	BOD		TOC		S. Solids	
			Untreated (lbs/day)	Treated (lbs/day)	Untreated (lbs/day)	Treated (lbs/day)	Untreated (lbs/day)	Treated (lbs/day)
Pentagon	42,400	1.06	2,100	360	1,000	300	2,100	310
Arlington	246,700	19.30	32,200	5,400	12,400	3,400	35,400	6,600
Sewer overflow D. C. system	—	2.50	2,800	2,800	1,800	1,800	3,300	3,300
District of Columbia	1,750,000	273.00	305,000	94,000	204,700	83,300	370,000	119,000
Alexandria	190,000	23.60	50,000	11,300	15,200	4,400	51,400	11,500
Fairfax Westgate	124,400	11.83	24,900	12,200	16,300	6,200	20,000	8,200
Piscataway	50,000	7.26	6,850	360	3,000	670	7,700	670
Andrews AFB No.1	11,000*	0.73	1,400	155	320	130	380	60
Andrews AFB No.2	11,000*	0.08	100	15	30	10	35	10
Fairfax Hunting Creek	24,900	3.39	5,000	1,500	2,500	800	4,200	1,100
Fairfax Dogue Creek	19,100	2.23	3,800	800	1,500	500	3,300	700
Ft. Belvoir No.1	3,550	0.59	1,100	120	430	75	110	70
Ft. Belvoir No.2	18,400	2.34	3,500	380	2,200	310	3,800	325
Total	2,480,450	347.91	438,750	129,390	261,380	101,895	501,725	151,845

* total for both plants

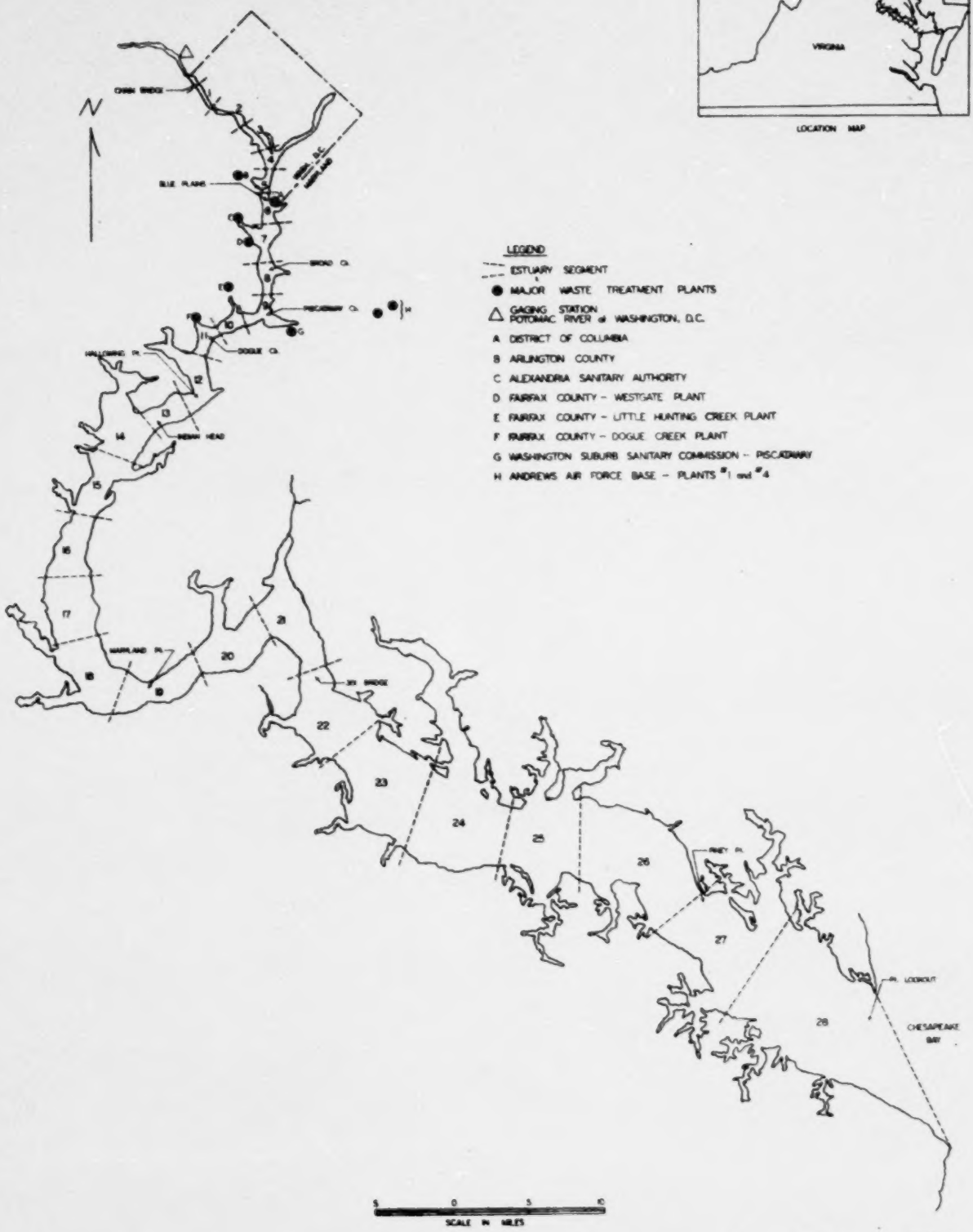
TABLE III-[illegible]

NITROGEN AND PHOSPHORUS
WASTEWATER LOADINGS
Potomac Estuary Intensive Survey
August 11-15, 1969

Facility	Flow (mgd)	T. Phos. as P		TKN		NH_3 as N	NO_2 - NO_3 as N	T. Nitrogen
		Untreated (lbs/day)	Treated (lbs/day)	Untreated (lbs/day)	Treated (lbs/day)	Treated (lbs/day)	Treated (lbs/day)	Treated (lbs/day)
Pentagon	1.06	60	50	440	220	140	80	300
Arlington	23.60	1,510	990	4,800	3,030	2,220	920	3,950
Sewer overflow D. C. system	2.50	200	200	410	410	270	0	410
District of Columbia	273.00	21,300	16,600	46,000	37,000	29,000	1,450	38,450
Alexandria	19.42	2,000	1,540	4,580	3,370	2,320	50	3,420
Fairfax Westgate	11.83	1,120	960	3,140	2,540	1,480	50	2,690
Piscataway	7.26	365	160	1,650	240	200	390	630
Andrews AFB No.1	0.73	50	45	70	50	40	30	80
Andrews AFB No.2	0.08	6	4	12	3	2	3	6
Fairfax Hunting Creek	3.39	275	270	720	550	430	25	575
Fairfax Dogue Creek	2.23	200	180	465	280	230	40	320
Ft. Belvoir No.1	0.59	25	15	145	30	20	55	85
Ft. Belvoir No.2	2.34	130	105	960	480	310	170	650
Total	347.91	27,241	21,119	63,392	48,200	36,642	3,263	51,463



LOCATION MAP



POTOMAC ESTUARY

011<

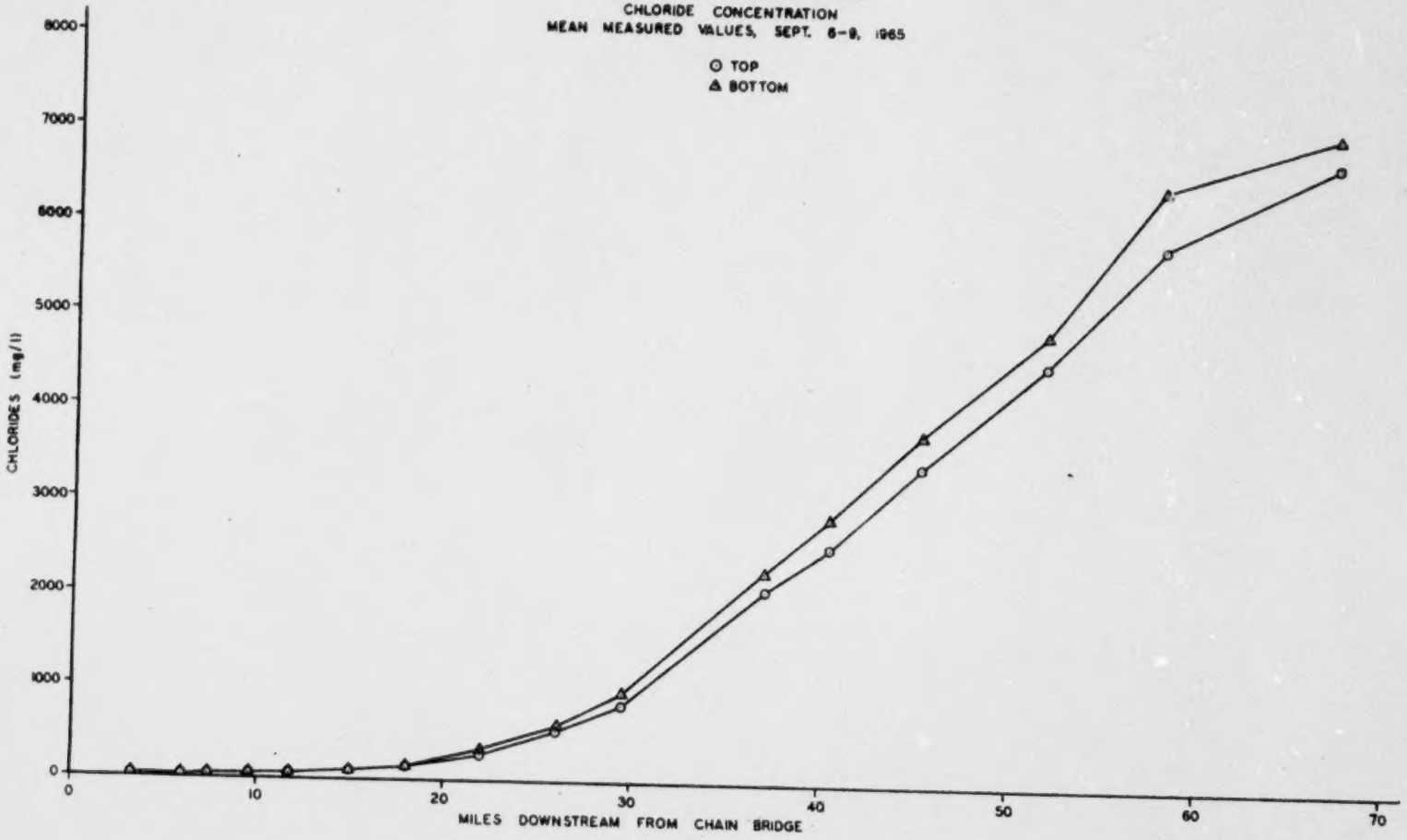

POTOMAC ESTUARY
MEAN FRESH WATER FLOW 780 cfs
CHLORIDE CONCENTRATION
MEAN MEASURED VALUES, SEPT. 6-9, 1965
O TOP
Δ BOTTOM
CHLORIDES (mg/l)
8000
7000
6000
5000
4000
3000
2000
1000
0
0
10
20
30
40
50
60
70
MILES DOWNSTREAM FROM CHAIN BRIDGE

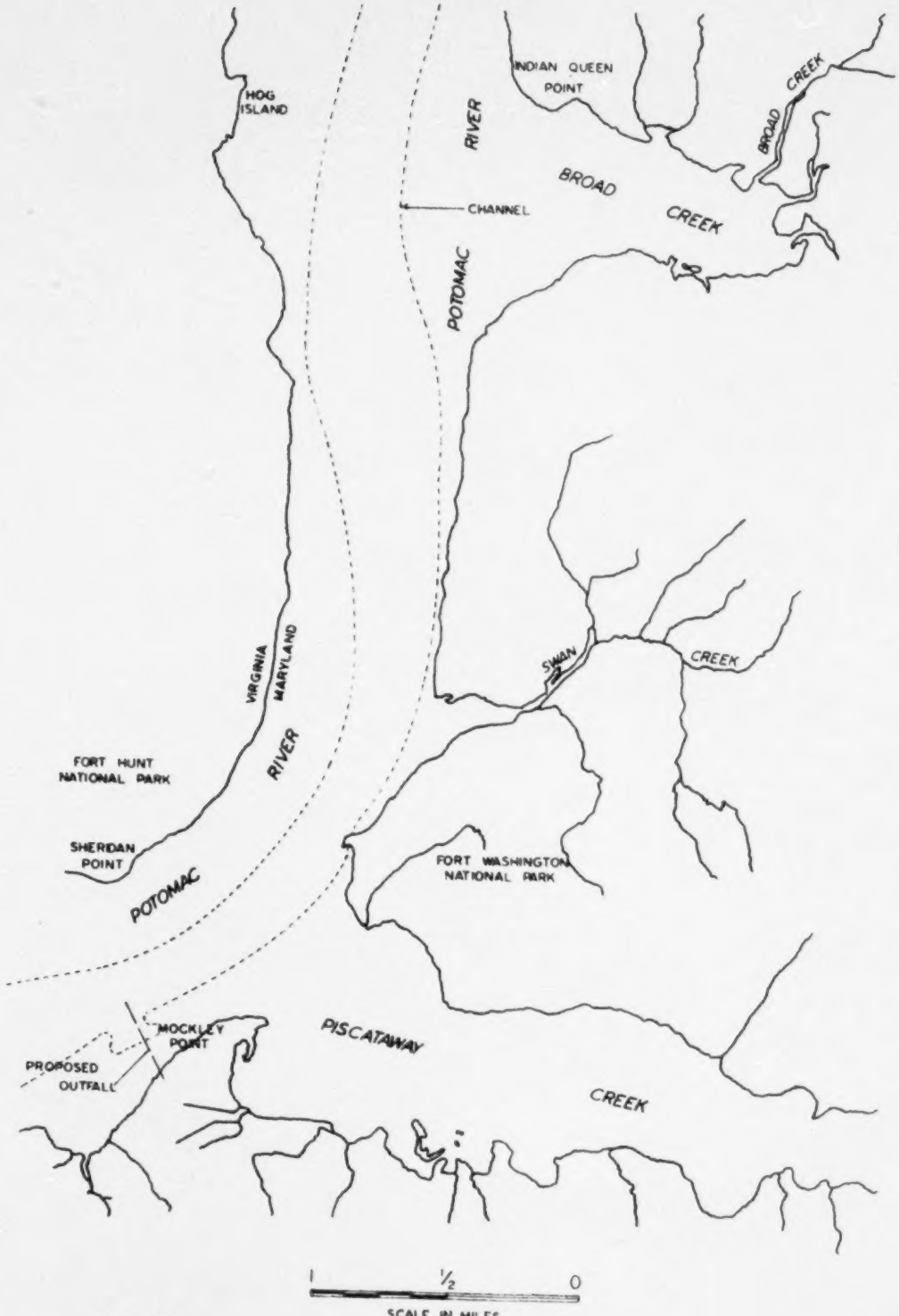
FIGURE III-2

Figure III-3 shows the Piscataway embayment and its location along the estuary which is about 18.2 miles from Chain Bridge. The embayment is about 2.6 miles long with an average depth of 4 feet and a width averaging from 2,000 to 4,000 feet.

The Piscataway Creek watershed has a drainage area of 81.5 square miles. The maximum, mean, and minimum flows for a stream gaging station established in 1965 near Piscataway, Maryland, with a drainage area of 39.5 square miles, were approximately 328, 20, and 0 cfs, respectively. Using the longer term records for Henson Creek, with a drainage area of 16.7 square miles in the adjacent watershed, the average annual flow for the entire watershed was estimated to be about 90 cfs.

Using a tidal prism height of 2.4 feet and a surface area of 39,100,000 square feet, 93,840,000 cubic feet of water, or about 700 million gallons enter and leave Piscataway embayment during each tidal cycle. This tidal movement of about 2,000 cfs, when compared to the average fresh water flow of 90 cfs, is one of the main driving forces for most of the mixing and transport of any pollutant in the lower portion of the embayment near the confluence with the Potomac Estuary.

POTOMAC ESTUARY
near the
PISCATAWAY EMBAYMENT



C14<

FIGURE III - 3

CHAPTER IV

SURFACE DYE RELEASE NEAR PROPOSED POTOMAC OUTFALL LOCATION

The intrusion of a pollutant into the Piscataway embayment from the proposed outfall of the Washington Suburban Sanitary Commission facility was simulated by a surface dye release. Use of aerial photography as a means of supplementing fluorometric dye studies was also investigated during the release.

A. RELEASE CONDITIONS

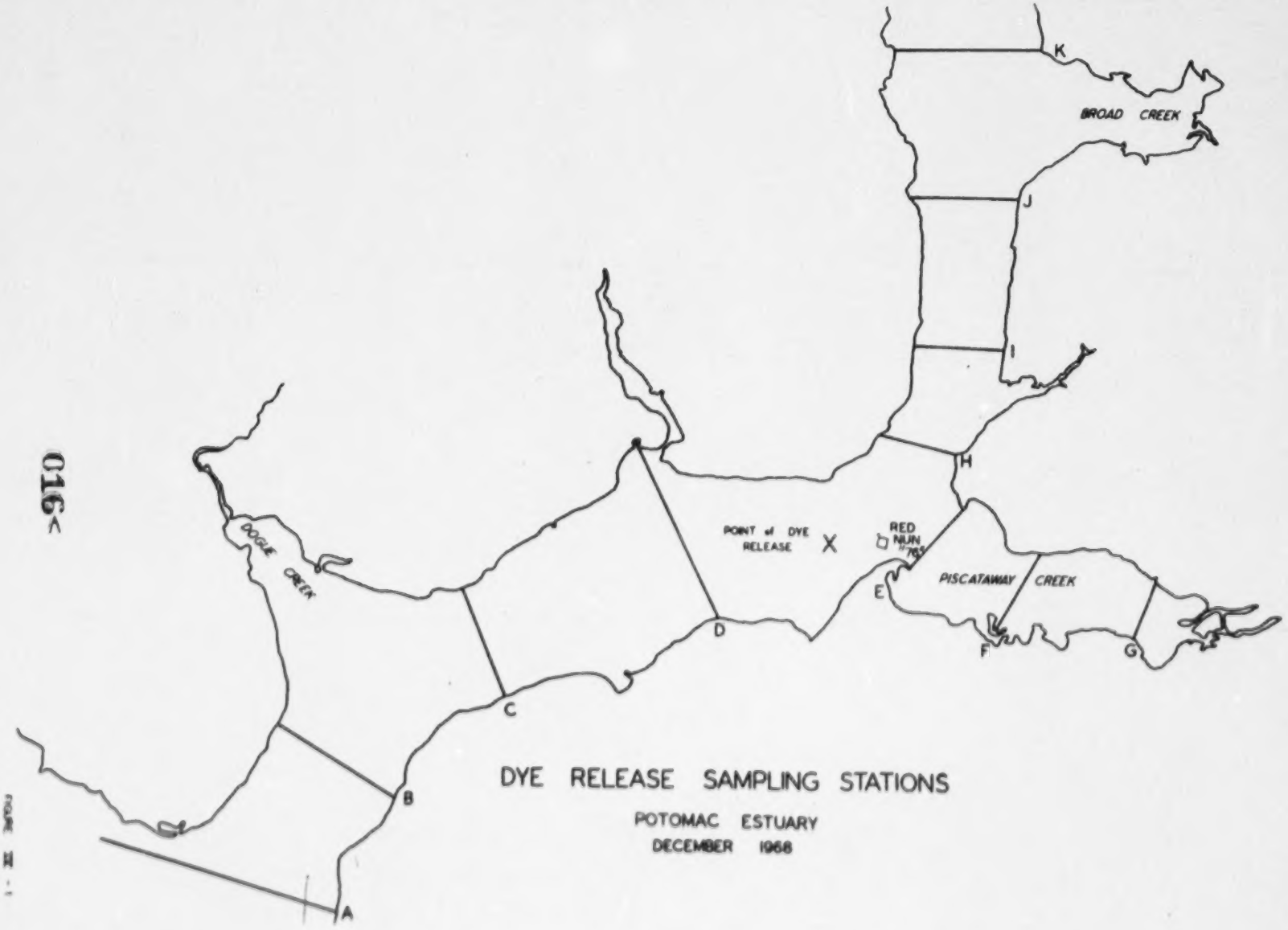
Approximately 1,000 feet from the shoreline and in about 20 feet of water, 250 pounds of Rhodamine WT dye were released instantaneously at the surface of the site of the proposed outfall in the Potomac channel. A map of the area shows the release point (Figure IV-1). The red channel marker "N 76" was used as the primary reference point.

To simulate the flow of the effluent into the embayment under the most adverse conditions, the release was made during low slack water or when the tidal velocity was zero following a low tide.* On December 10, 1968, the following were the tidal stages for the Potomac near Fort Washington:

Low tide	6:06 a.m.
Low slack water	6:47 a.m.
Time of dye dump	8:00 a.m.**

* In the Potomac Estuary, low slack water lags low tide by about 3/4 of an hour

** The release was scheduled for 6:47 a.m. but was delayed by ice conditions



DYE RELEASE SAMPLING STATIONS

POTOMAC ESTUARY

DECEMBER 1968

Figure IV-2 is a graphical presentation of tidal conditions for the release date.

B. TRANSECT LOCATIONS AND MONITORING SYSTEM

During the first flood tidal stage, dispersion and movement of the dye were monitored using both analytical measurements of concentration at predetermined transects and visually from a helicopter. During the two days following the release, only analytical measurements were made.

1. Analytical Measurements

To facilitate dye detection, eight transects in the Potomac Estuary and three in the Piscataway embayment were established. (Figure IV-1) Discrete samples were taken at various depths and locations across each transect.

The concentration of dye in the samples was measured using a fluorometer equipped with excitation and light emission filter designed to measure selectively the fluorescence of the dye being used. With this tracer measurement system, a sensitivity of about 0.01 parts per billion (ppb) was attained.

2. Visual Monitoring

As an experiment, visual observations were also made of the dye movement from a helicopter. Photographs were taken at elevations varying from 300 to 600 feet using Ektachrome high speed color film at shutter speeds of about 1/500 of a second. Flights were made at 8:00 a.m., 9:00 a.m., 10:00 a.m., 11:00 a.m., 1:00 p.m., and 3:00 p.m. The weather was clear except for some cloud cover

during the 3:00 p.m. flight.

C. ANALYSIS OF DYE RELEASE DATA

As can be seen in Figures IV-3, IV-4, and IV-5, the dye moved upstream hugging the Maryland shoreline at the confluence of the Piscataway embayment and the estuary upstream near Fort Washington. This caused a slight dye intrusion into and out of the Piscataway embayment resulting in a horseshoe configuration.

During flood tide, the movement of dye in this configuration was from the southern shore to the northern shore as shown in Figure IV-5. A slight intrusion into Swan Creek can also be seen in Figure IV-4.

At 11:00 a.m., the upstream movement was about at its maximum limit with an upstream excursion of approximately 4.0 miles. To allow for the delay in starting, the total upstream movement was estimated to be about 4.5 miles.

In Figures IV-6 and IV-7, the downstream movement of dye can be seen during the first phase of ebb tide. High tidal currents in the main channel near Fort Washington caused the dye to disperse fairly rapidly. The net downstream movement during ebb tide was estimated to be about 5.3 miles. With this ebb tide excursion, the effluent from the proposed outfall would almost reach Gunston Cove.

During the afternoon flights, no significant dye concentrations were observed visually in the embayment. Some samples of water taken in the embayment during the afternoon sampling runs contained

very small concentrations of dye.

During the first tidal cycle, the dye layered at the surface. This appears to have been caused by the density difference between the cold water and the dye and to a lesser degree in the embayment by ice conditions.

After four complete tidal cycles, the dye was fairly well dispersed both vertically and horizontally. As can be seen in Figure IV-8, the concentration was in the main channel at the confluence.

When dye distribution configurations in Figures IV-3 through IV-7 are compared, it can readily be seen that during flood tide the bulk of dye remained relatively concentrated. However, during ebb tide, the dye appeared to diffuse and disperse much more rapidly. Lack of adequate fluorometer data makes accurate calculation of dispersion coefficients impossible.

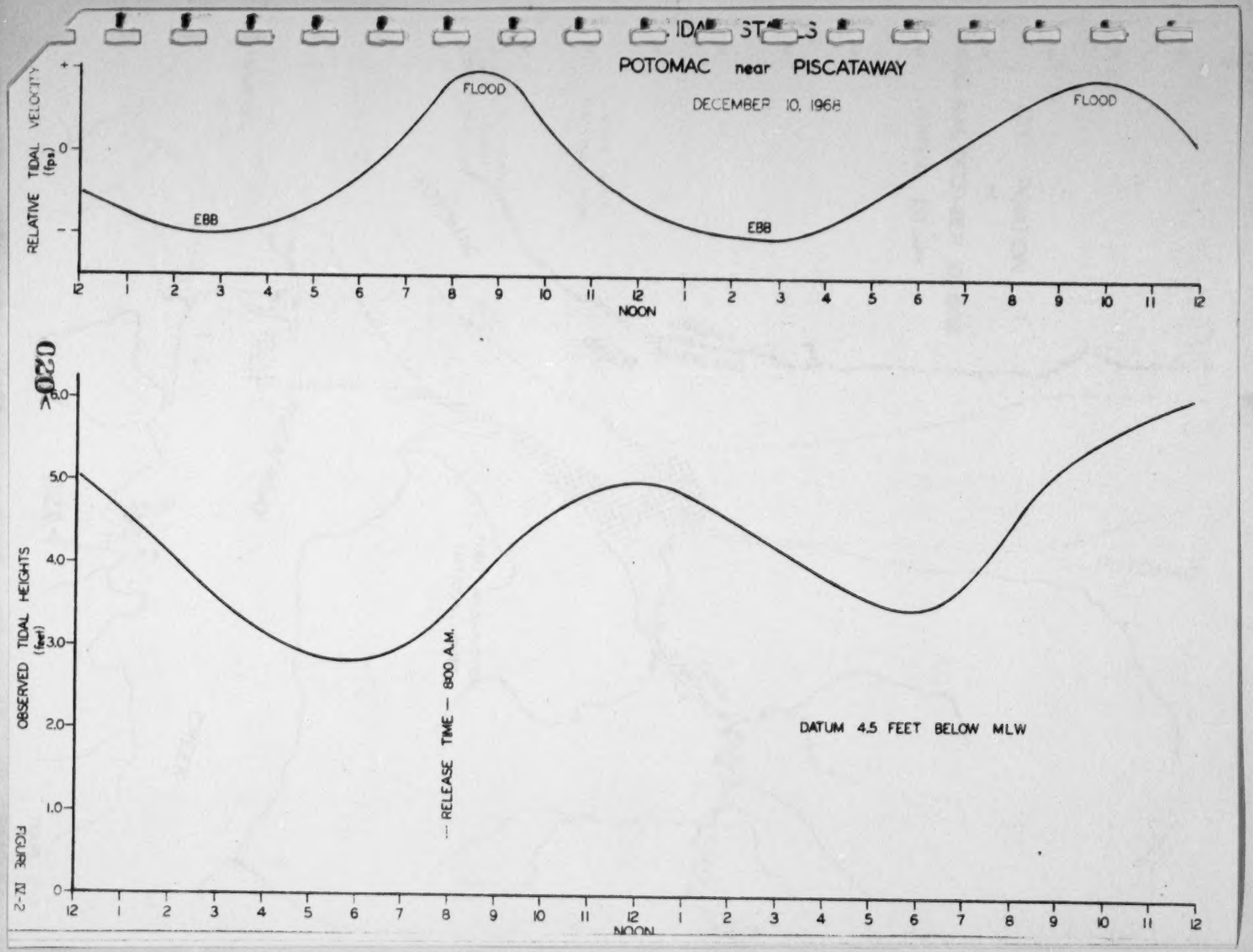

POTOMAC near PISCATAWAY
DECEMBER 10, 1968
RELATIVE TIDAL VELOCITY (fps)
+
0
-
FLOOD
EBB
EBB
FLOOD
12 1 2 3 4 5 6 7 8 9 10 11 12 1 2 3 4 5 6 7 8 9 10 11 12
NOON
OBSERVED TIDAL HEIGHTS (feet)
6.0
5.0
4.0
3.0
2.0
1.0
0
RELEASE TIME — 800 A.M.
DATUM 4.5 FEET BELOW MLW
12 1 2 3 4 5 6 7 8 9 10 11 12 1 2 3 4 5 6 7 8 9 10 11 12
NOON

FIGURE IX-2

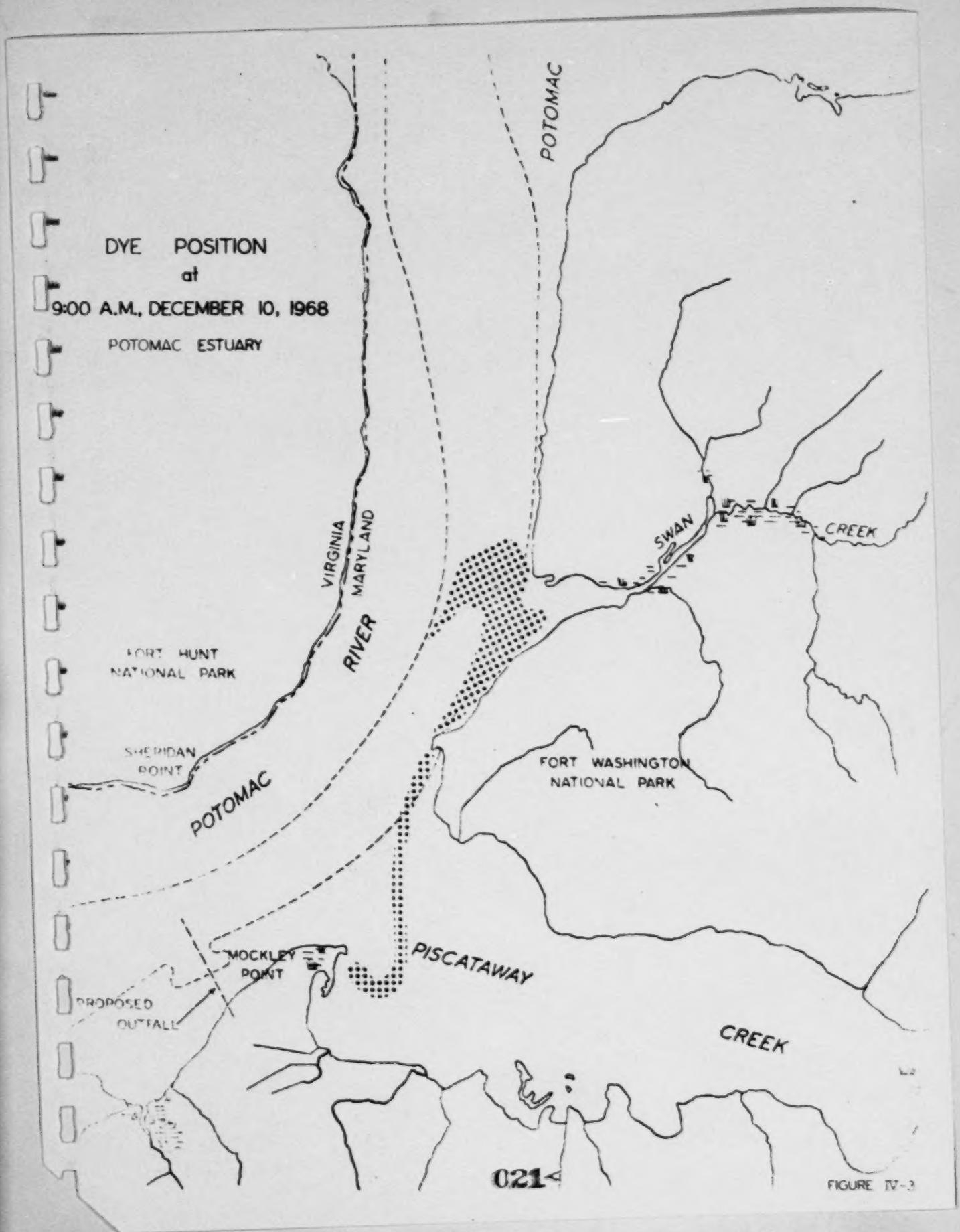

DYE POSITION
at
9:00 A.M., DECEMBER 10, 1968
POTOMAC ESTUARY
POTOMAC
VIRGINIA
MARYLAND
RIVER
SWAN
CREEK
FORT HUNT
NATIONAL PARK
SHERIDAN
POINT
POTOMAC
FORT WASHINGTON
NATIONAL PARK
MOCKLEY
POINT
PISCATAWAY
PROPOSED
OUTFALL
CREEK

FIGURE IV-3

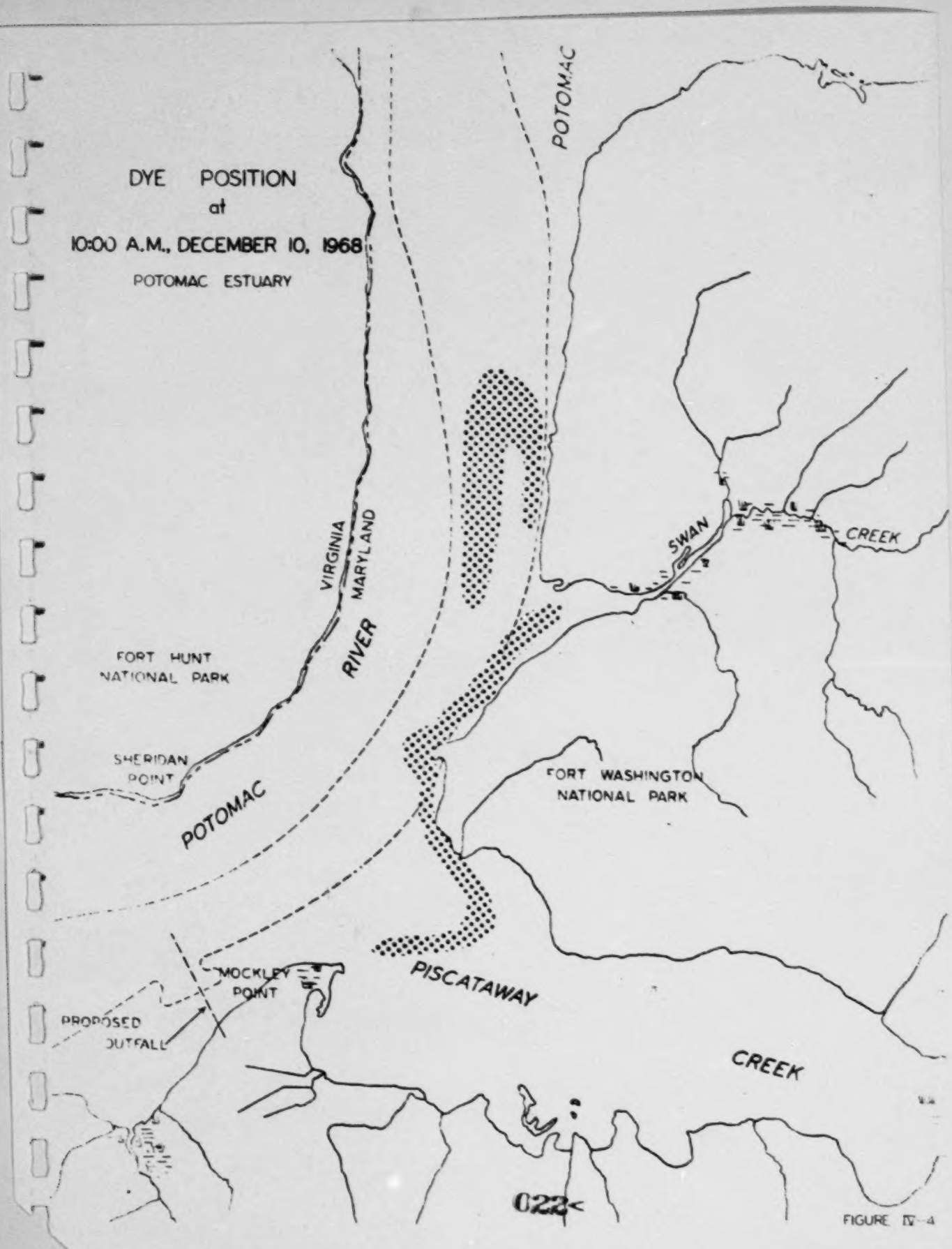

DYE POSITION
at
10:00 A.M., DECEMBER 10, 1968
POTOMAC ESTUARY
POTOMAC
VIRGINIA
MARYLAND
RIVER
SWAN
CREEK
FORT HUNT
NATIONAL PARK
SHERIDAN
POINT
POTOMAC
FORT WASHINGTON
NATIONAL PARK
MOCKLEY
POINT
PROPOSED
OUTFALL
PISCATAWAY
CREEK
022

FIGURE IV-4

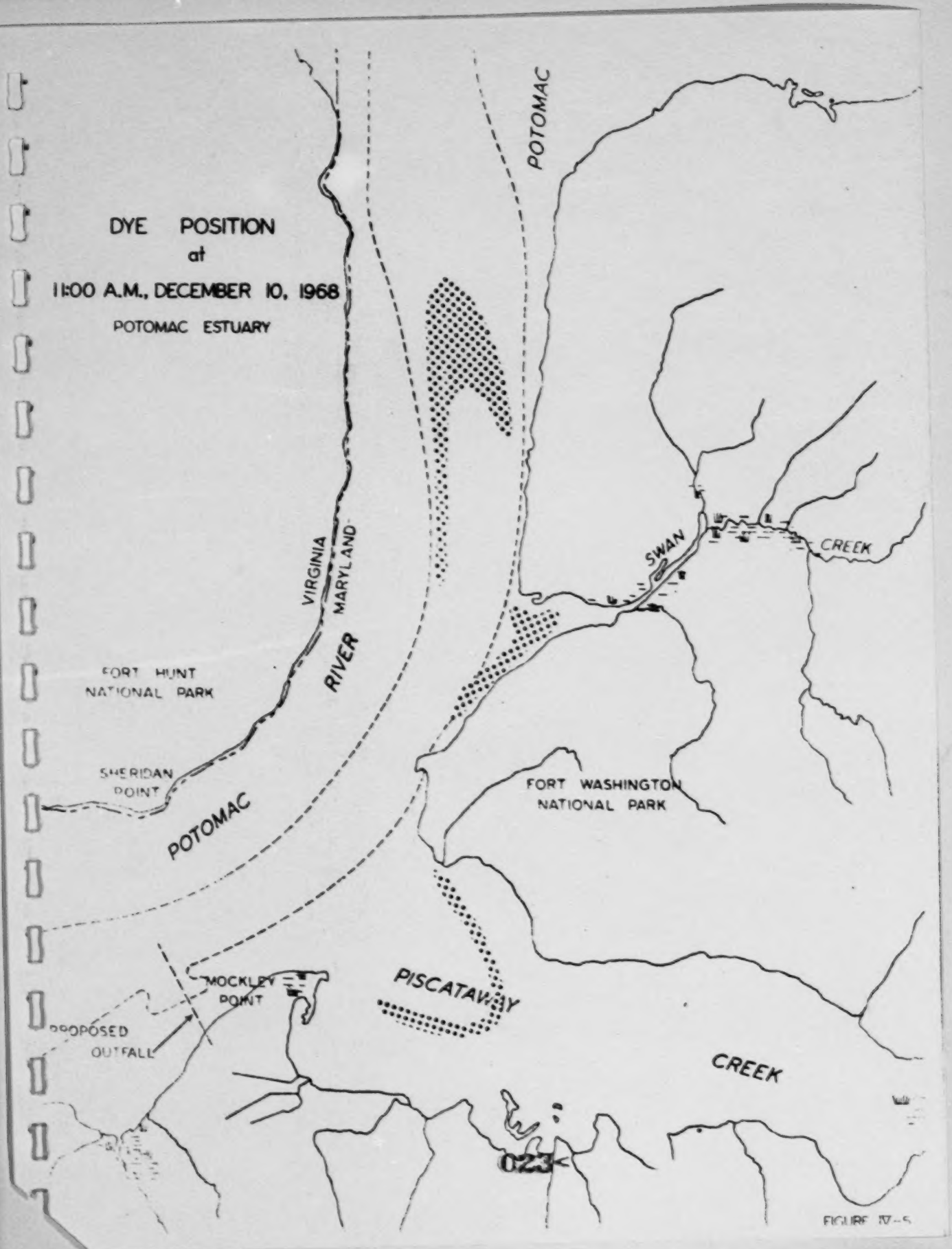

DYE POSITION
at
11:00 A.M., DECEMBER 10, 1968
POTOMAC ESTUARY
POTOMAC
VIRGINIA
MARYLAND
RIVER
SWAN
CREEK
FORT HUNT
NATIONAL PARK
SHERIDAN
POINT
POTOMAC
FORT WASHINGTON
NATIONAL PARK
MOCKLEY
POINT
PROPOSED
OUTFALL
PISCATAWAY
CREEK
023

FIGURE IV-5

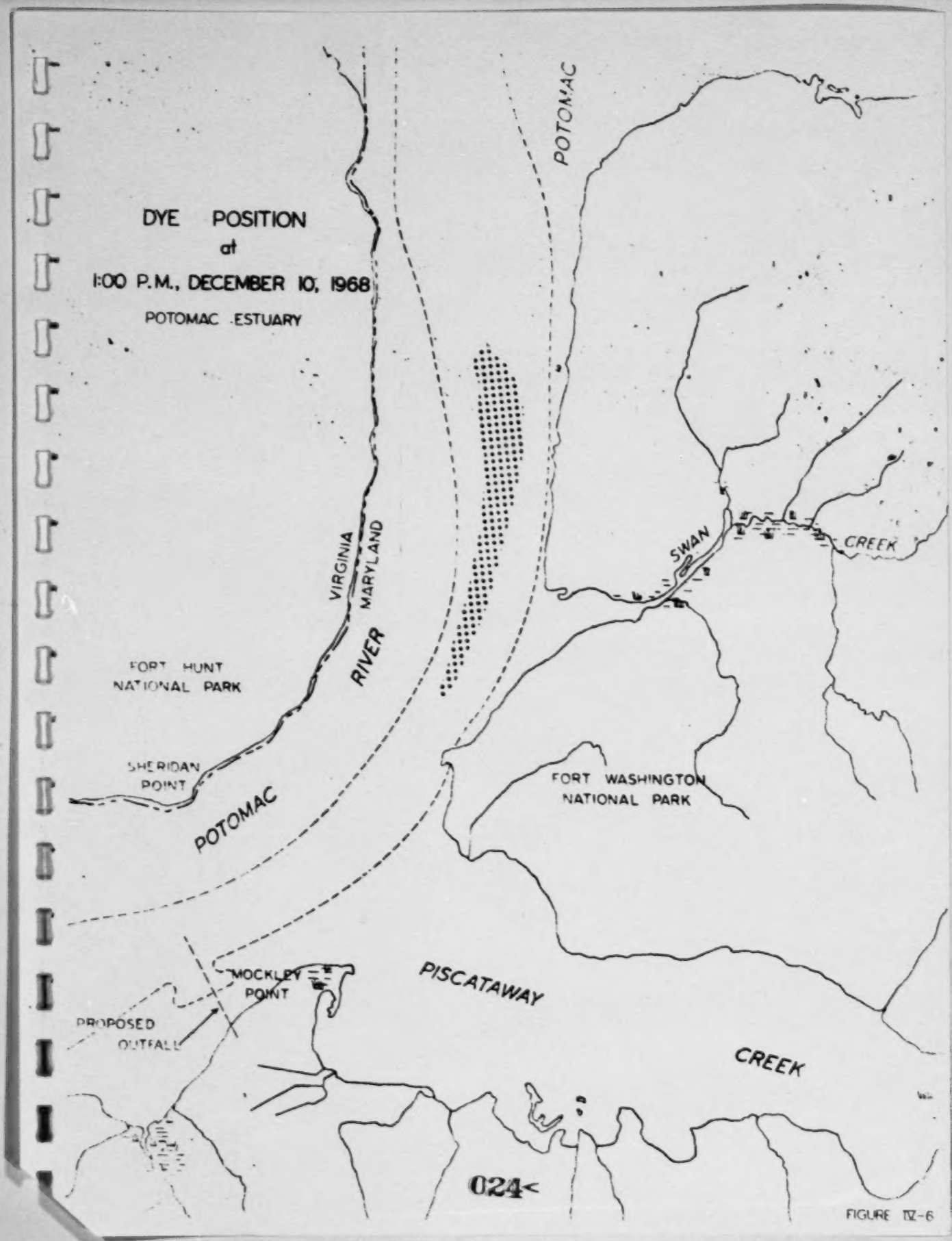

DYE POSITION
at
1:00 P.M., DECEMBER 10, 1968
POTOMAC ESTUARY
POTOMAC
VIRGINIA
MARYLAND
RIVER
SWAN
CREEK
FORT HUNT
NATIONAL PARK
SHERIDAN
POINT
POTOMAC
FORT WASHINGTON
NATIONAL PARK
MOCKLEY
POINT
PISCATAWAY
PROPOSED
OUTFALL
CREEK

FIGURE IV-6

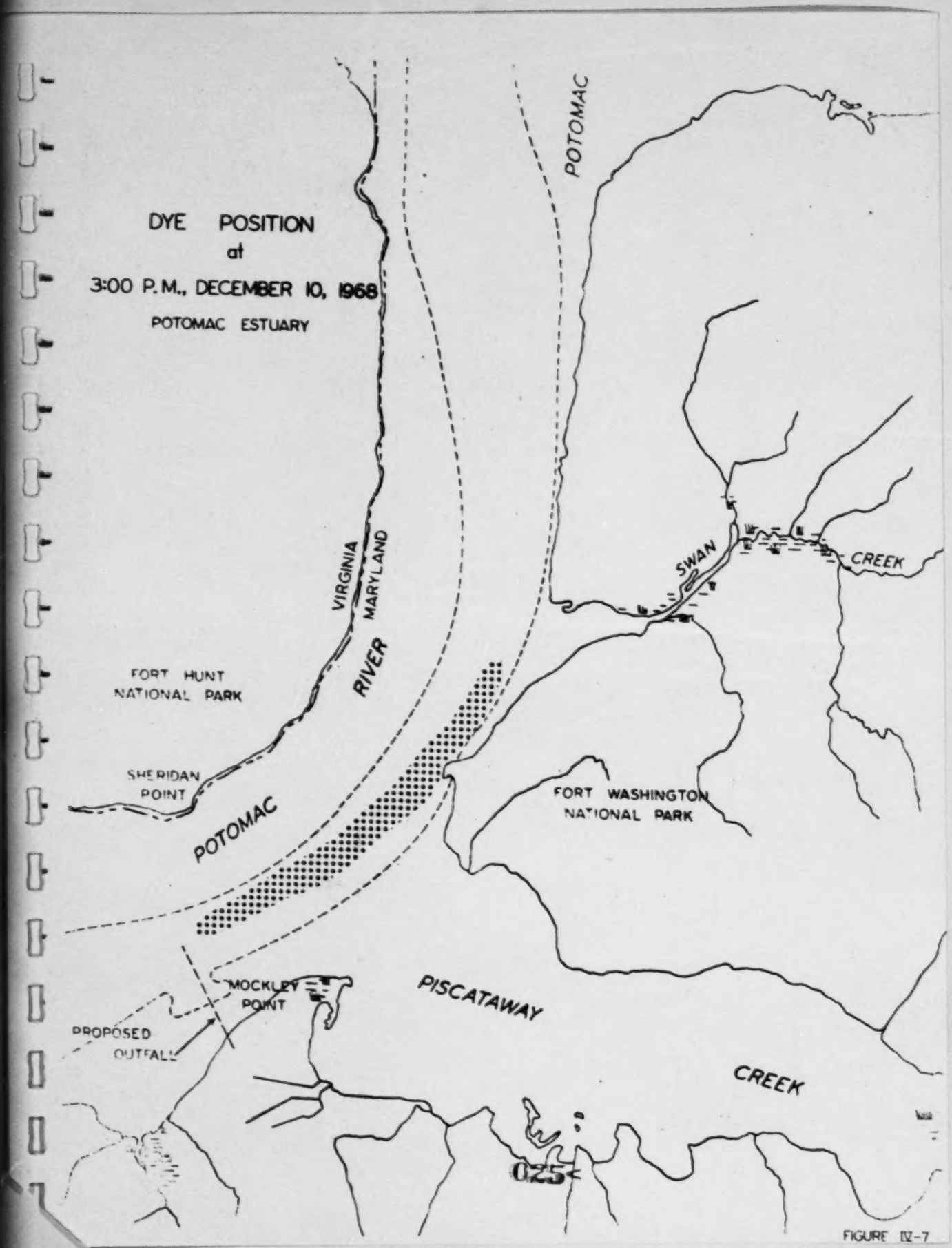

DYE POSITION
at
3:00 P.M., DECEMBER 10, 1968
POTOMAC ESTUARY
POTOMAC
VIRGINIA
MARYLAND
RIVER
SWAN
CREEK
FORT HUNT
NATIONAL PARK
SHERIDAN
POINT
POTOMAC
FORT WASHINGTON
NATIONAL PARK
MOCKLEY
POINT
PROPOSED
OUTFALL
PISCATAWAY
CREEK
025

FIGURE IV-7

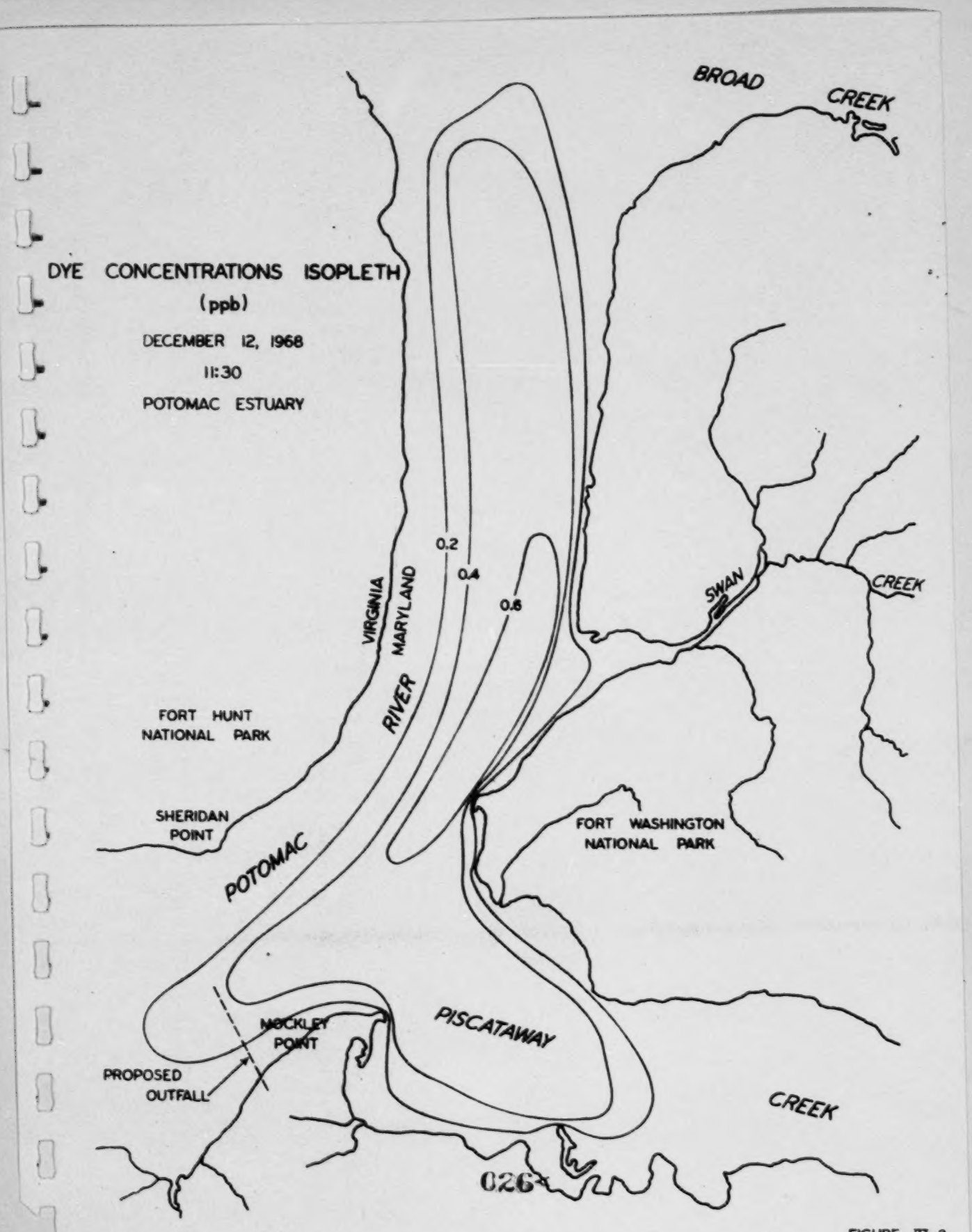

DYE CONCENTRATIONS ISOPLETH
(ppb)
DECEMBER 12, 1968
11:30
POTOMAC ESTUARY
BROAD
CREEK
0.2
0.4
0.8
VIRGINIA
MARYLAND
RIVER
SWAN
CREEK
FORT HUNT
NATIONAL PARK
SHERIDAN
POINT
POTOMAC
FORT WASHINGTON
NATIONAL PARK
MOCKLEY
POINT
PISCATAWAY
PROPOSED
OUTFALL
CREEK

FIGURE IV-8

CHAPTER V

SUBSURFACE RELEASE NEAR PROPOSED POTOMAC OUTFALL LOCATION

The direct intrusion of a pollutant into the embayment, time of travel, and the dispersion characteristics of the upper Potomac Estuary were simulated by a subsurface release.

A. RELEASE CONDITIONS

On April 25, 1969, 750 pounds of 20 percent concentration of Rhodamine WT dye were instantaneously released during low tide at 9:00 a.m. The dye was pumped down to a depth of 40 feet below the surface about 1,500 feet from the shoreline in the same general location as the previous release (Figure IV-1). The average fresh water flow into the estuary during the release was about 4,700 cfs.

B. TRANSECT LOCATIONS AND MONITORING SYSTEM

Samples were taken at all points indicated in Table V-1 and shown in Figure IV-1. Monitoring was done on a daily basis, either by CTSL personnel or by Steuart Petroleum Company personnel in conjunction with a nutrient transport study. The dye was followed for 22 days to provide the necessary data required to determine the objectives of the study.

C. ANALYSIS OF DYE RELEASE DATA

1. Dye Intrusion

During the first flood tide following the release, no dye was detected in the embayment. About one hour after the release a considerable amount of dye was observed at the surface in the main channel of the Potomac Estuary near the Fort Washington lighthouse.

Table V-1

POTOMAC ESTUARY SAMPLING STATIONS
April 25, 1969
Dye Studies

Station	Miles From Chain Bridge
A	14.6
B	15.6
C	17.1
D	17.6
H	18.2
J	19.4
K	20.4
L	21.6
M	22.5
N	24.3
O	24.8
P	26.0
Q	26.3
R	27.2
S	29.5

Based upon fluorometric readings, it appears that considerable quantities of dye came to the surface as a result of turbulence caused by a change in channel direction and elevation. As with the first release, the maximum excursion during flood tide was about 4.5 miles reaching a point just below Broad Creek.

On April 26, 1969, or two complete tidal cycles after the release, the dye was still visually detectable near the release point and along the shoreline near Mount Vernon. Fluorometric readings confirmed these visual observations.

Figure V-1 shows the intrusion of the dye into the Piscataway embayment after two complete tidal cycles. The dye remained close to the southern side of the embayment with very little dye moving upstream.

A comparison of Figures V-1 and IV-3 indicates that movement of dye from surface and subsurface releases at the proposed location of the outfall will result in intrusion into the embayment (visible and measured) to 3,700 feet from the confluence of the embayment and the Potomac.

2. Time of Travel

Time of travel is an important parameter in determining the position of a pollutant and in calculating the residual of any non-conservative pollutant.

Figures V-2 through V-11 present spacial plots of dye for various sampling periods. The rate of movement of peak concentration can be

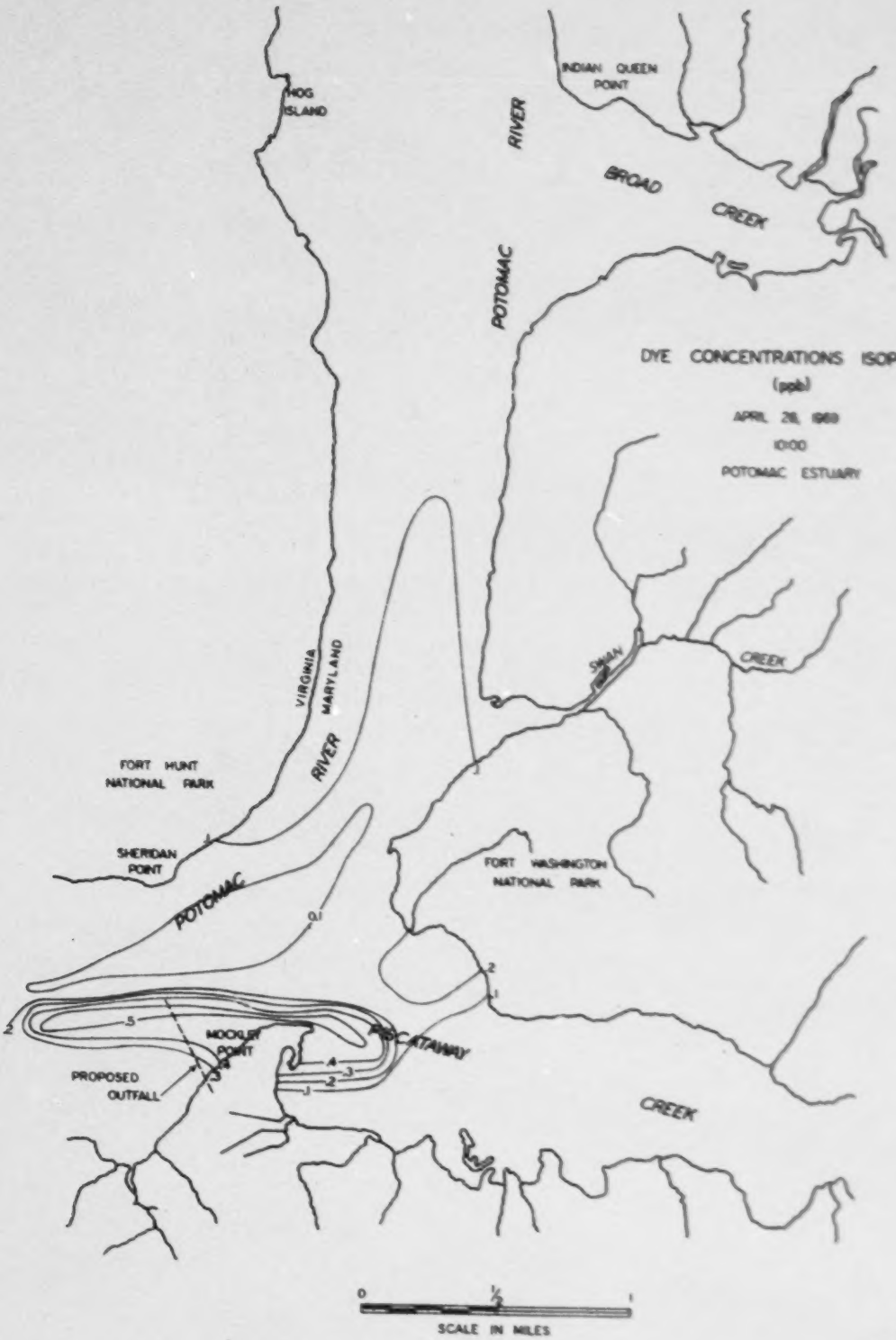

HOG ISLAND
INDIAN QUEEN POINT
RIVER
BROAD CREEK
POTOMAC
DYE CONCENTRATIONS ISOPLETH
(ppb)
APRIL 28, 1969
10:00
POTOMAC ESTUARY
SWAN CREEK
VIRGINIA
MARYLAND
RIVER
FORT HUNT NATIONAL PARK
SHERIDAN POINT
POTOMAC
FORT WASHINGTON NATIONAL PARK
MOCKLEY POINT
PROPOSED OUTFALL
PISCATAWAY CREEK
0
½
1
SCALE IN MILES

FIGURE II-1

SPACIAL CONCENTRATION OF DYE

SAMPLING PERIOD 1145 - 1440
APRIL 30, 1969
LOW TIDE 1200

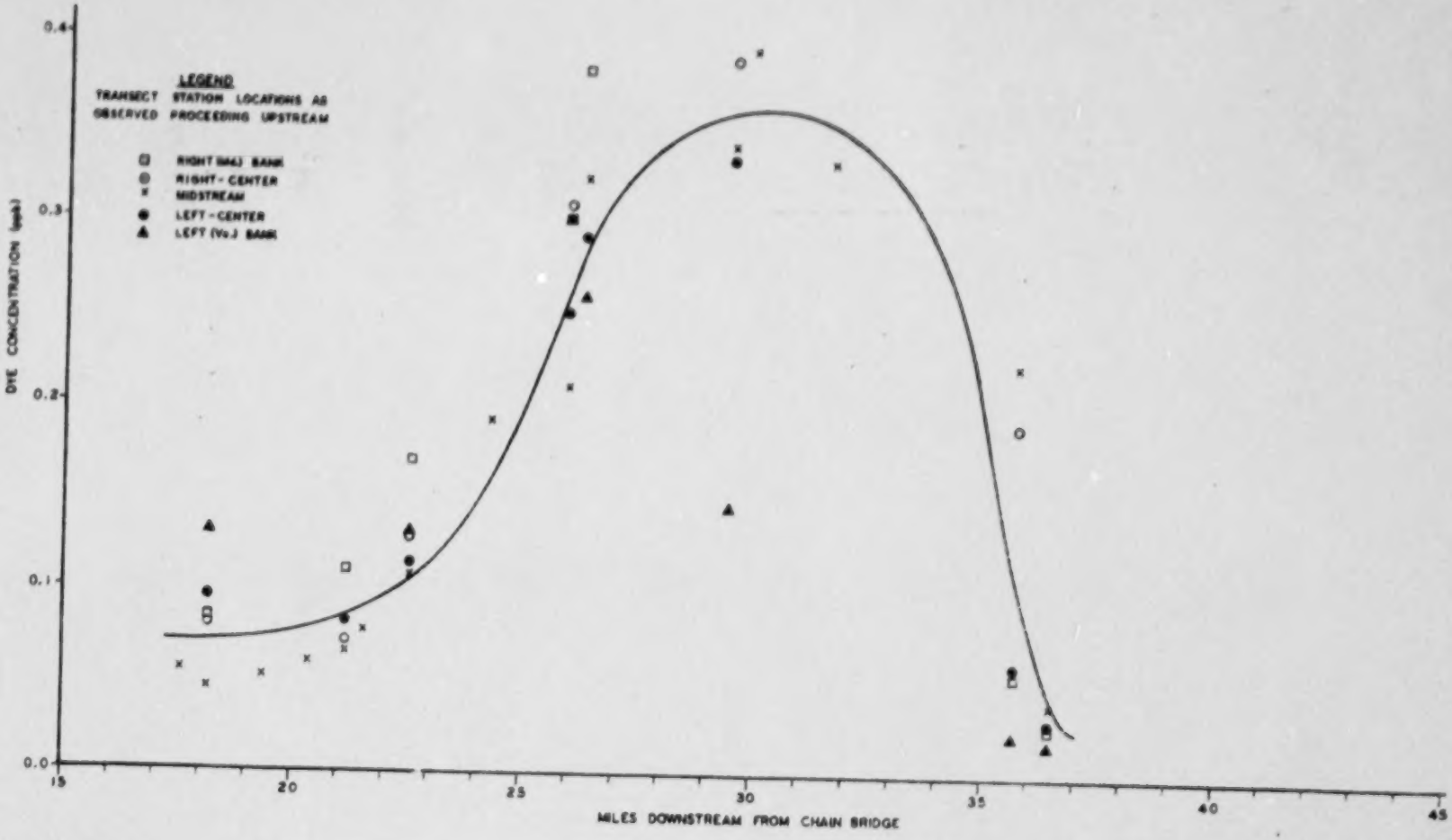


FIGURE II-2

SPACIAL CONCENTRATION OF DYE

SAMPLING PERIOD 1145 - 1425
MAY 2, 1969
LOW TIDE 1400

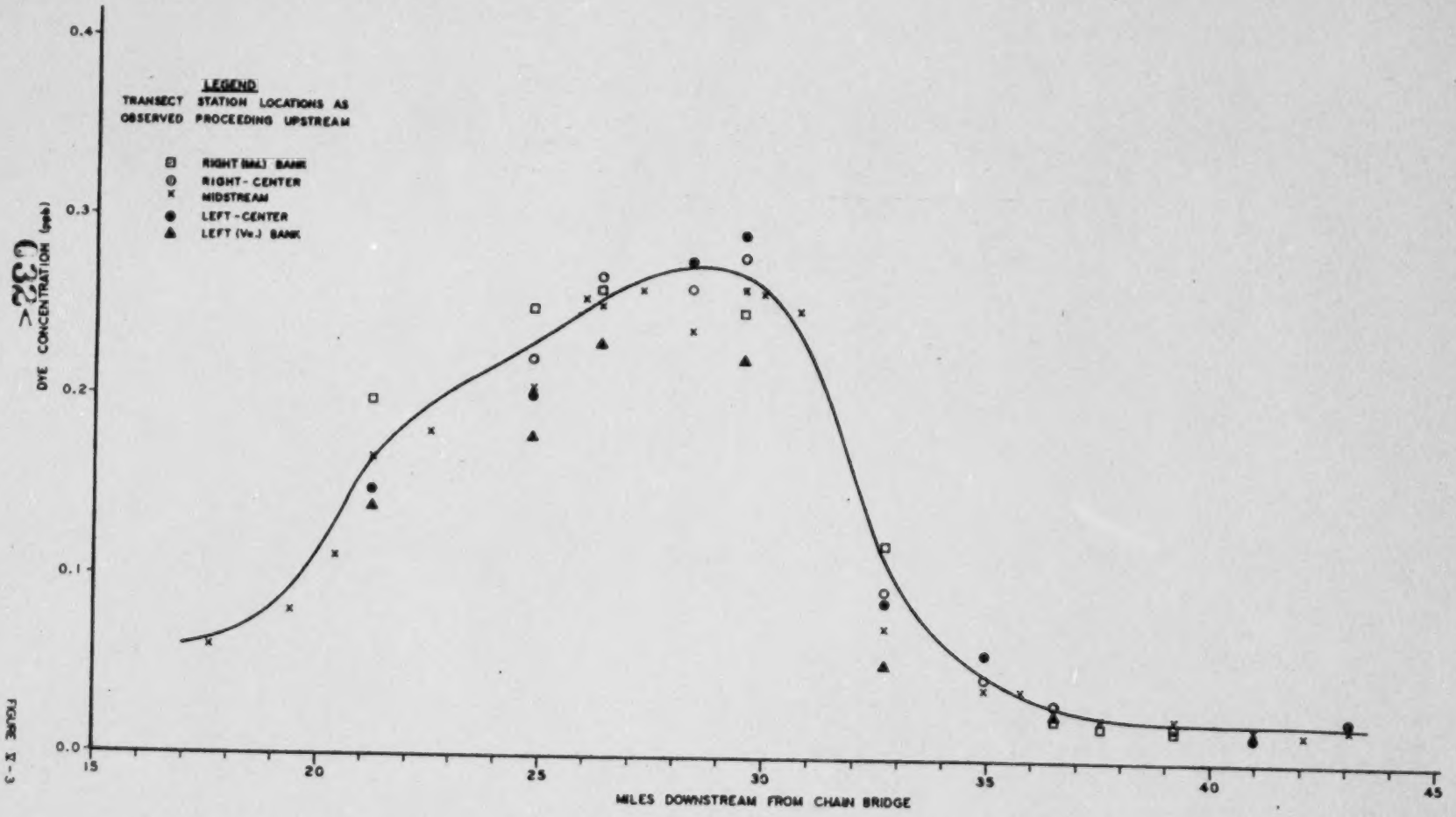


FIGURE X - 3

SPACIAL CONCENTRATION OF DYE

SAMPLING PERIOD 1143 - 1410

MAY 5, 1969

LOW TIDE 1600

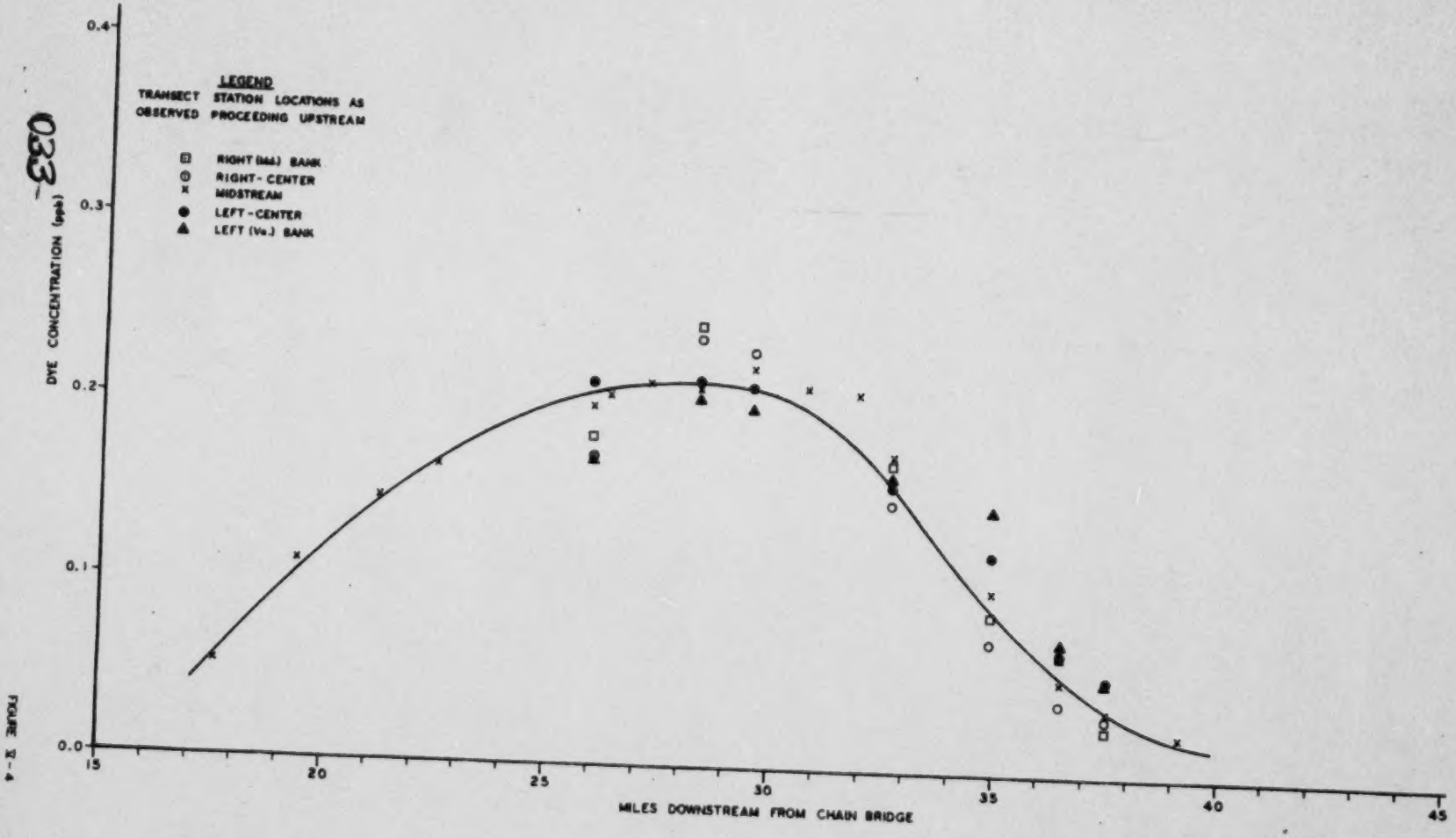
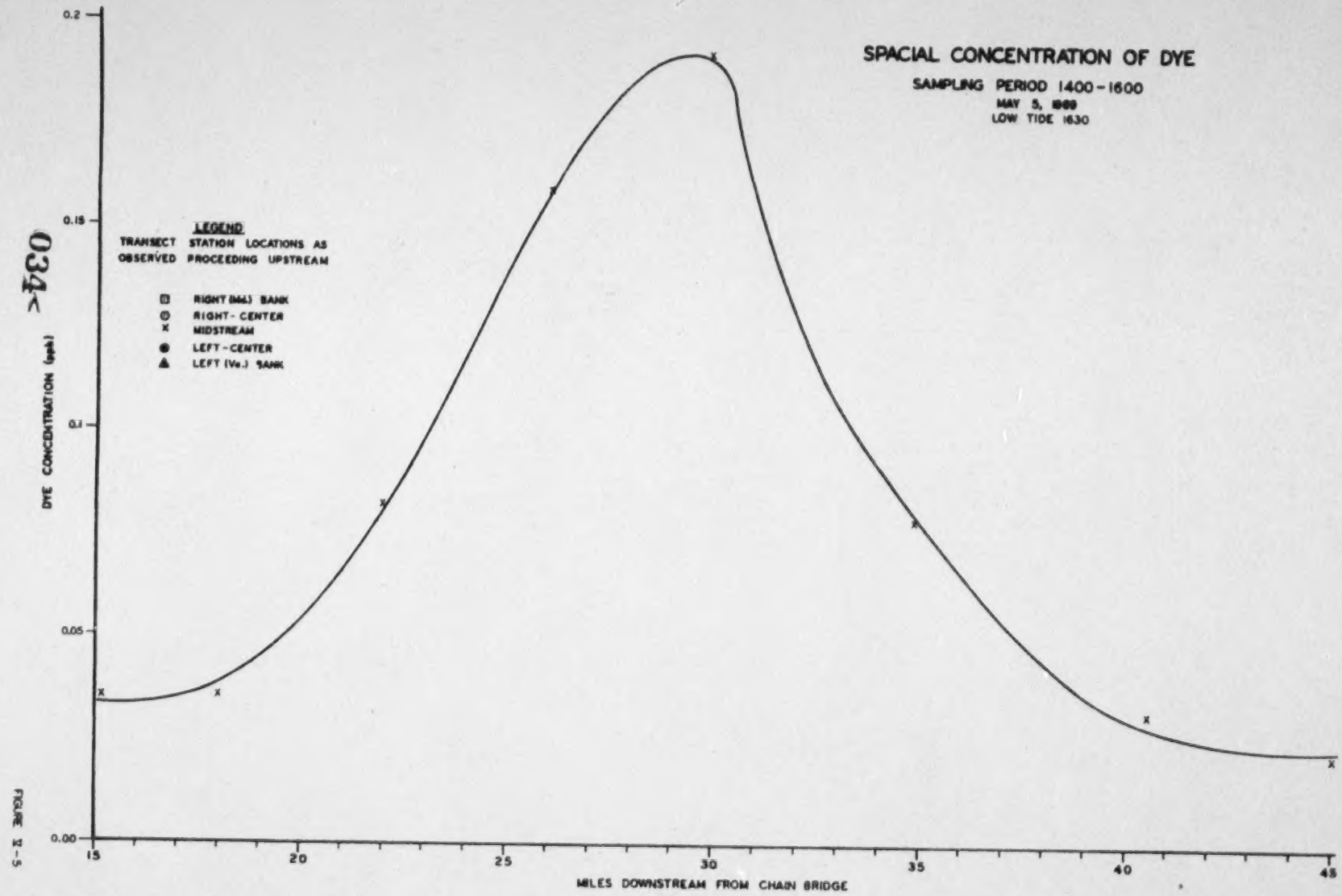
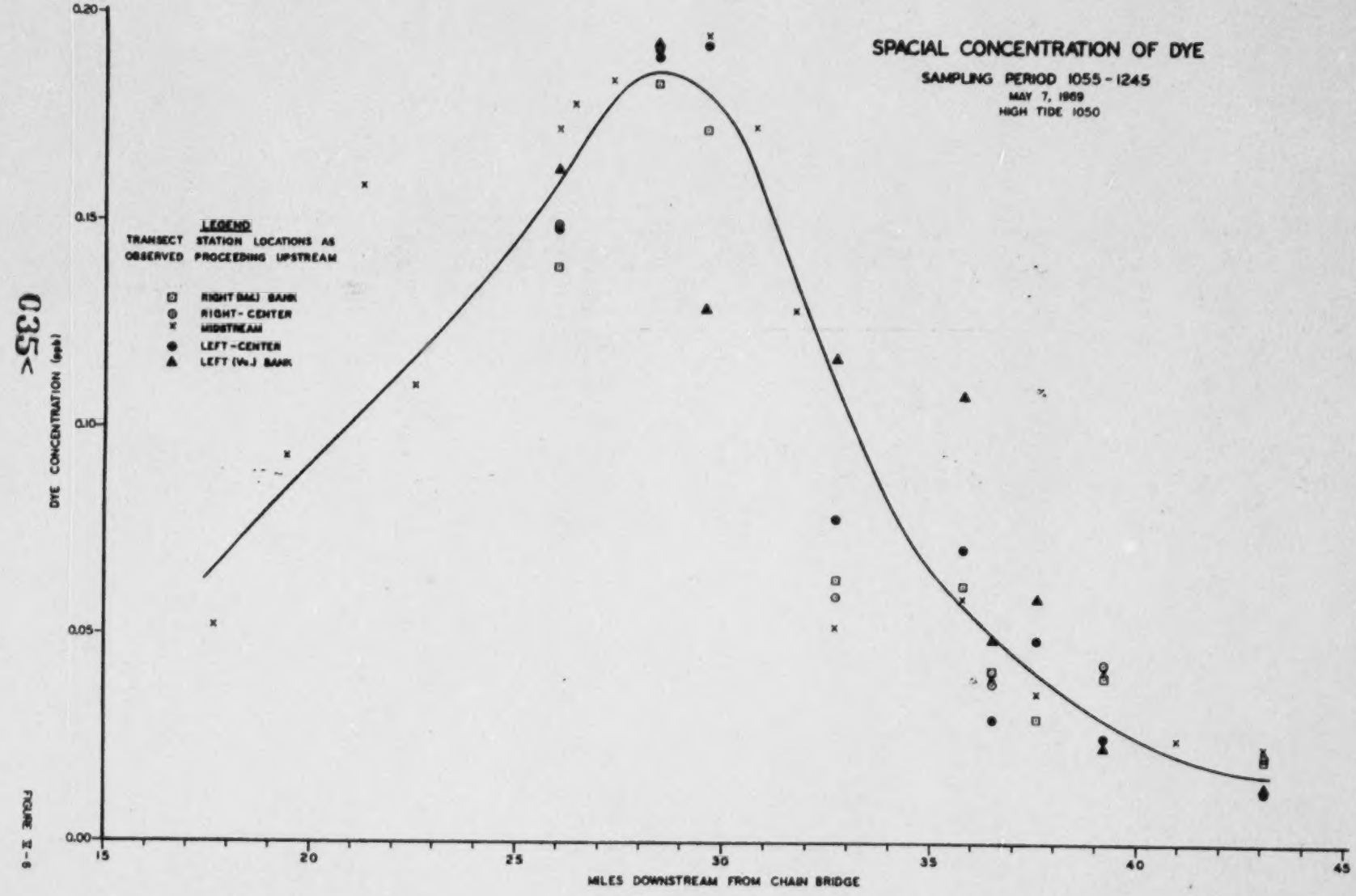


FIGURE X-4



034<

FIGURE II - 5



0.35<

FIGURE II-6

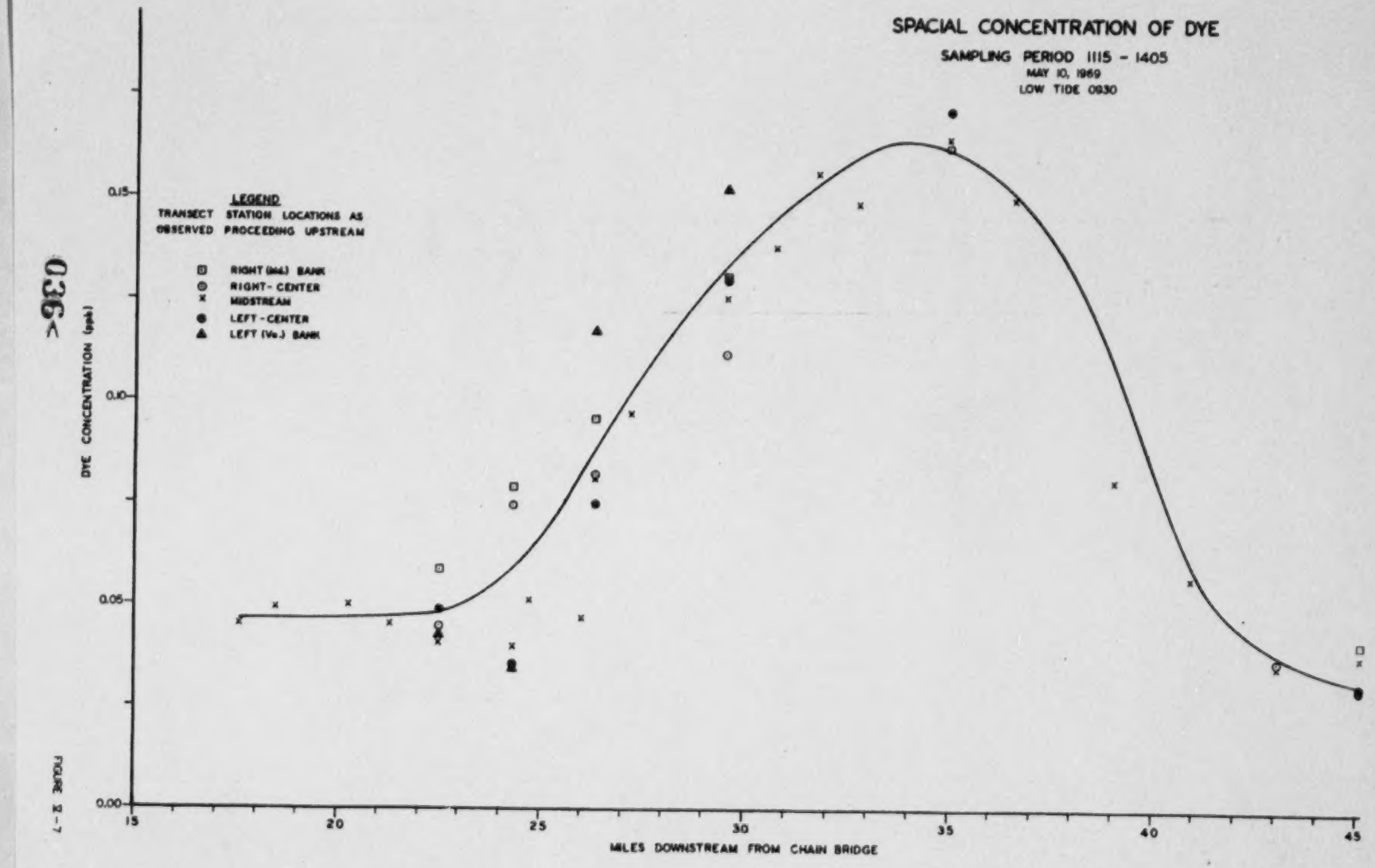


FIGURE 2-7

036

SPACIAL CONCENTRATION OF DYE

SAMPLING PERIOD 0400 - 0600
MAY 13, 1969
HIGH TIDE 0440

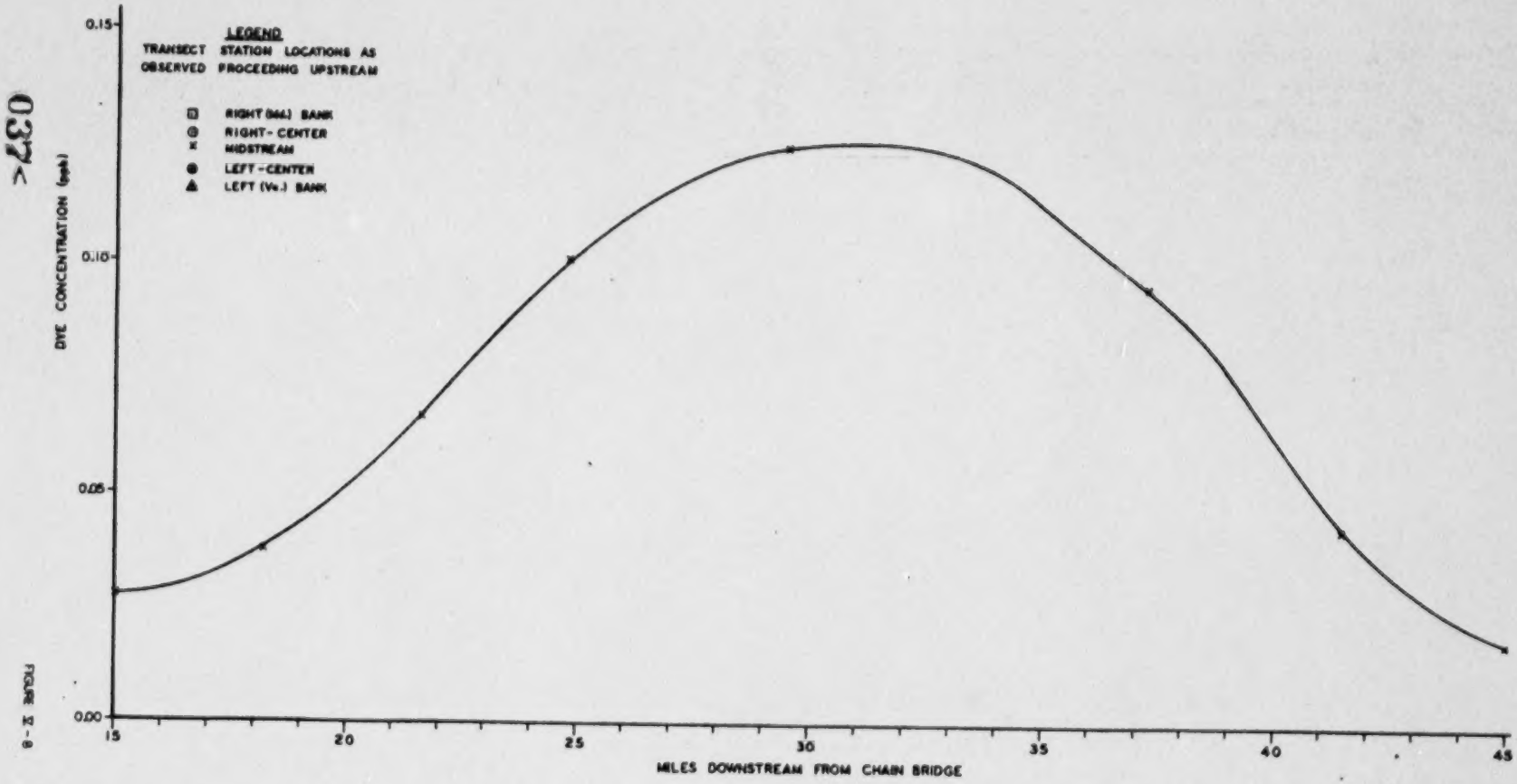
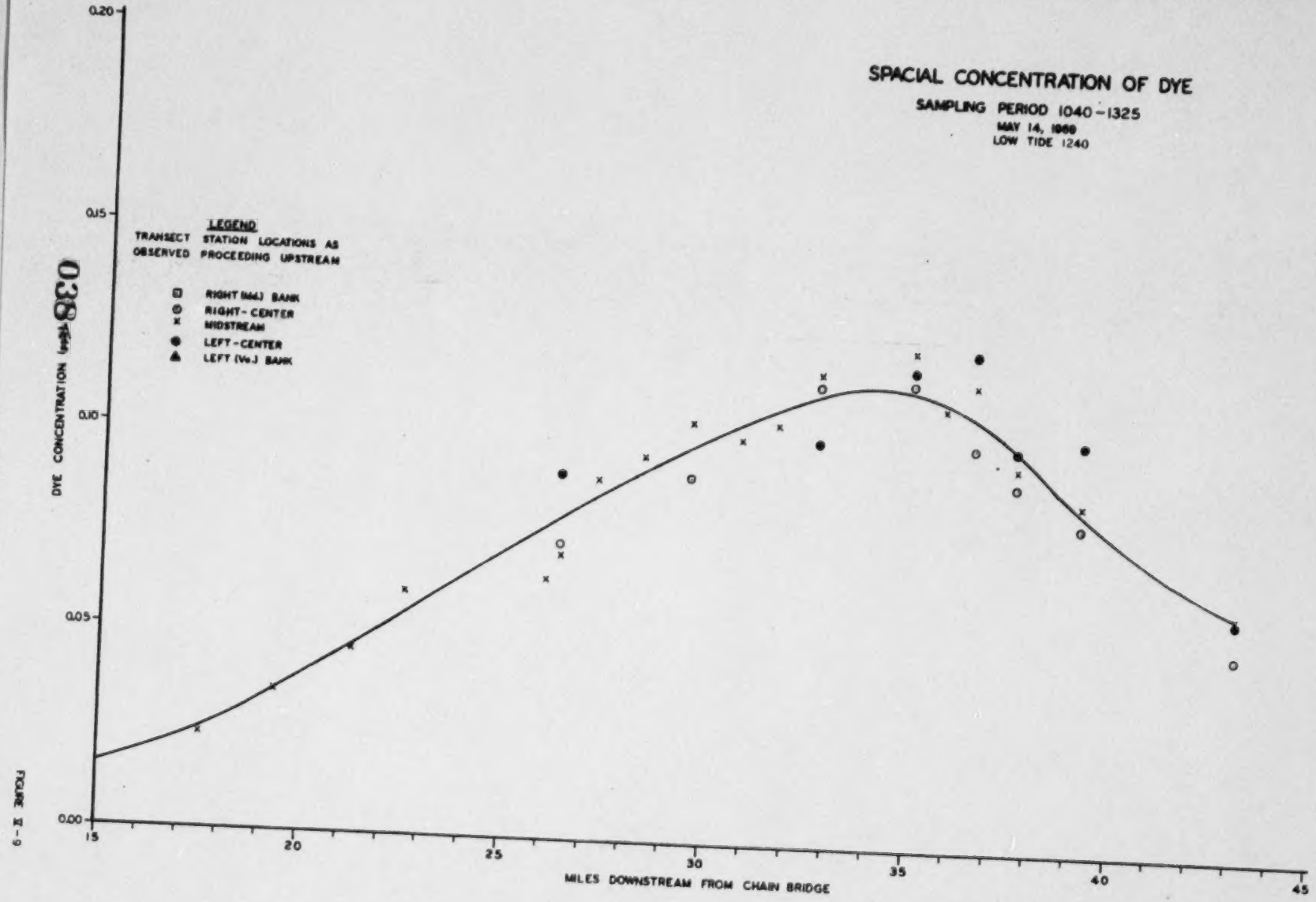


FIGURE II-8

037<

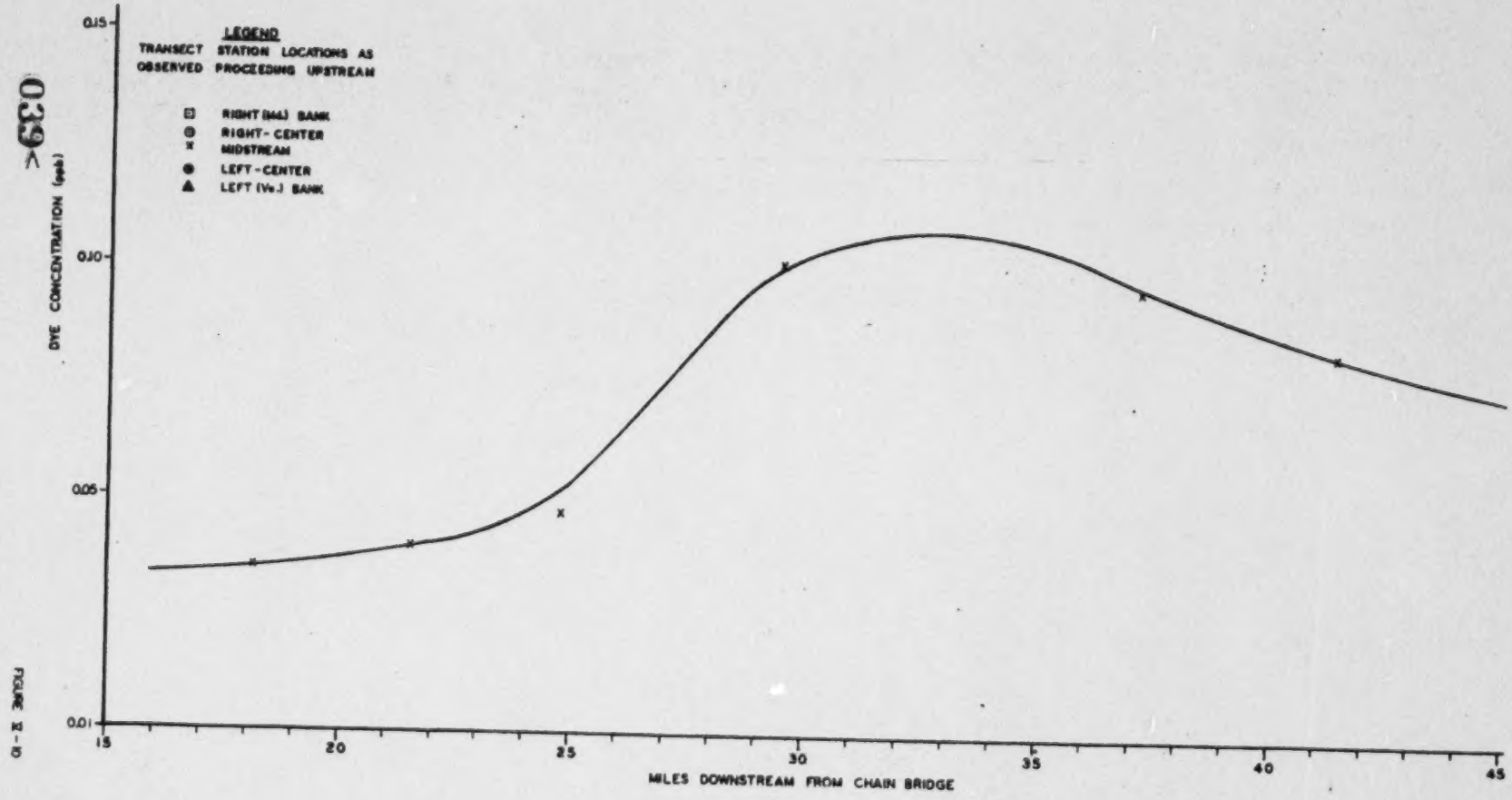


038

FIGURE II-9

SPACIAL CONCENTRATION OF DYE

SAMPLING PERIOD 1400-1600
MAY 20, 1969
LOW TIDE 1612

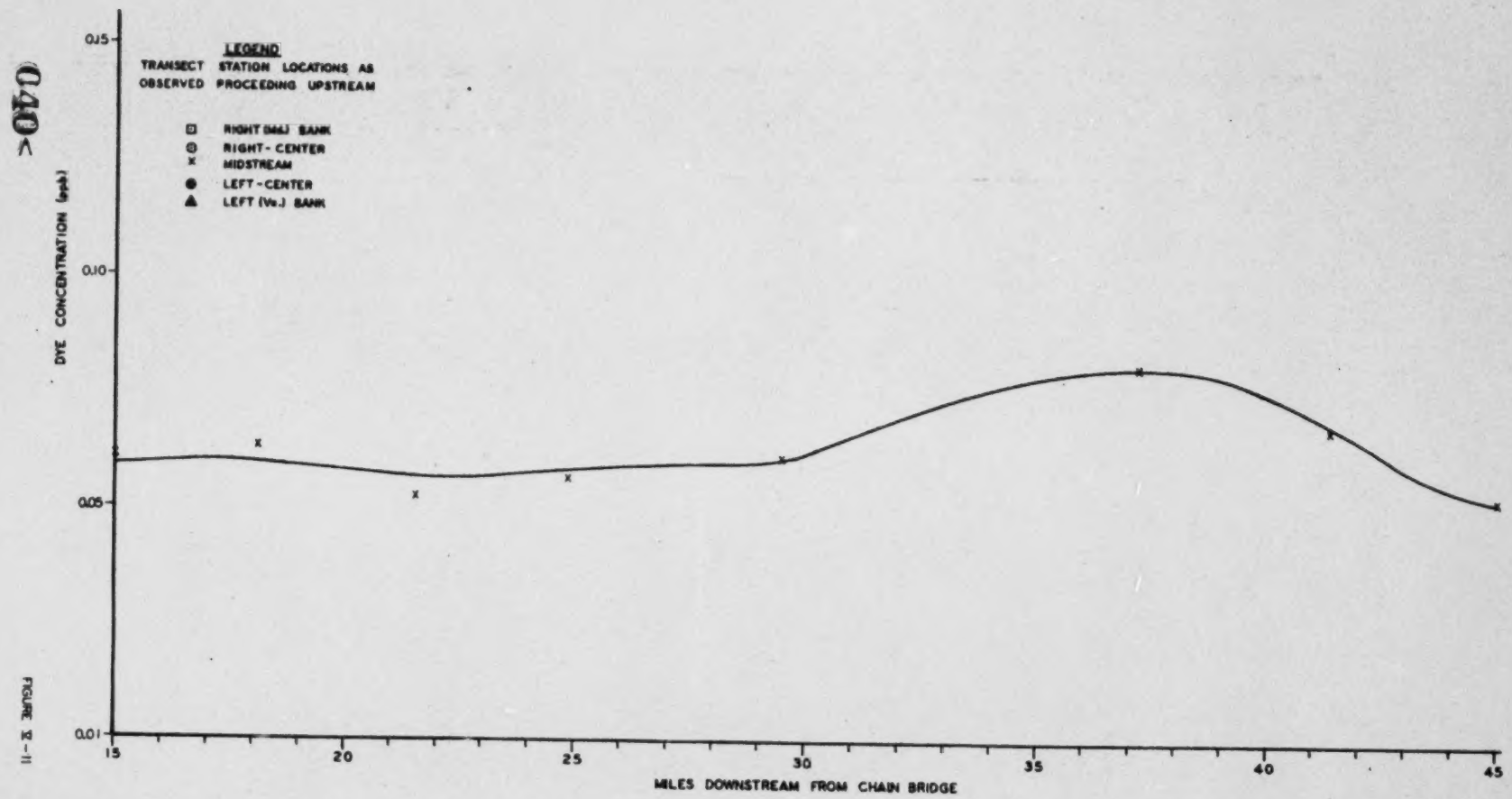


039

FIGURE II-13

SPACIAL CONCENTRATION OF DYE

SAMPLING PERIOD 2200-2400
MAY 26, 1969
LOW TIDE 2100



<0.40

FIGURE XI-11

determined by observing the positions of the peak concentration on the various spacial plots.

As can be seen in Figure V-12, the peak movement was greatly affected by tidal conditions. On April 29-30, northwest winds at a velocity of about 20 miles/hour caused extremely low tides. (See Figure V-13)

Compensating for the extremely low tides, an adjusted low tide peak movement is presented in Figure V-12. A comparison of the time-of-travel of the adjusted movement with the travel time as determined by a mathematical model of the estuary for a freshwater inflow of 5,000 cfs, indicates a fairly close agreement. It appears that the large peak movement caused by extreme tides was temporary.

As can also be seen in Figure V-12, the rate of movement or the advective velocity decreases with distance from Chain Bridge. The velocity in the vicinity of the Piscataway embayment was 1.4 mi/day as compared to about 0.5 mi/day at Indian Head.

3. Dispersion Coefficient

As indicated previously, the dispersion coefficient can serve as a parameter indicative of an estuary's ability to diffuse pollutants discharged from wastewater treatment facilities. The method of calculating the dispersion coefficient used in this report is the same as outlined by O'Connor [5] and is presented in the appendix.

For the sub-surface release, the calculated dispersion coefficients in the Potomac Estuary below the proposed Piscataway outfall ranged

determined by observing the positions of the peak concentration on the various spacial plots.

As can be seen in Figure V-12, the peak movement was greatly affected by tidal conditions. On April 29-30, northwest winds at a velocity of about 20 miles/hour caused extremely low tides. (See Figure V-13)

Compensating for the extremely low tides, an adjusted low tide peak movement is presented in Figure V-12. A comparison of the time-of-travel of the adjusted movement with the travel time as determined by a mathematical model of the estuary for a freshwater inflow of 5,000 cfs, indicates a fairly close agreement. It appears that the large peak movement caused by extreme tides was temporary.

As can also be seen in Figure V-12, the rate of movement or the advective velocity decreases with distance from Chain Bridge. The velocity in the vicinity of the Piscataway embayment was 1.4 mi/day as compared to about 0.5 mi/day at Indian Head.

3. Dispersion Coefficient

As indicated previously, the dispersion coefficient can serve as a parameter indicative of an estuary's ability to diffuse pollutants discharged from wastewater treatment facilities. The method of calculating the dispersion coefficient used in this report is the same as outlined by O'Connor [5] and is presented in the appendix.

For the sub-surface release, the calculated dispersion coefficients in the Potomac Estuary below the proposed Piscataway outfall ranged

>240

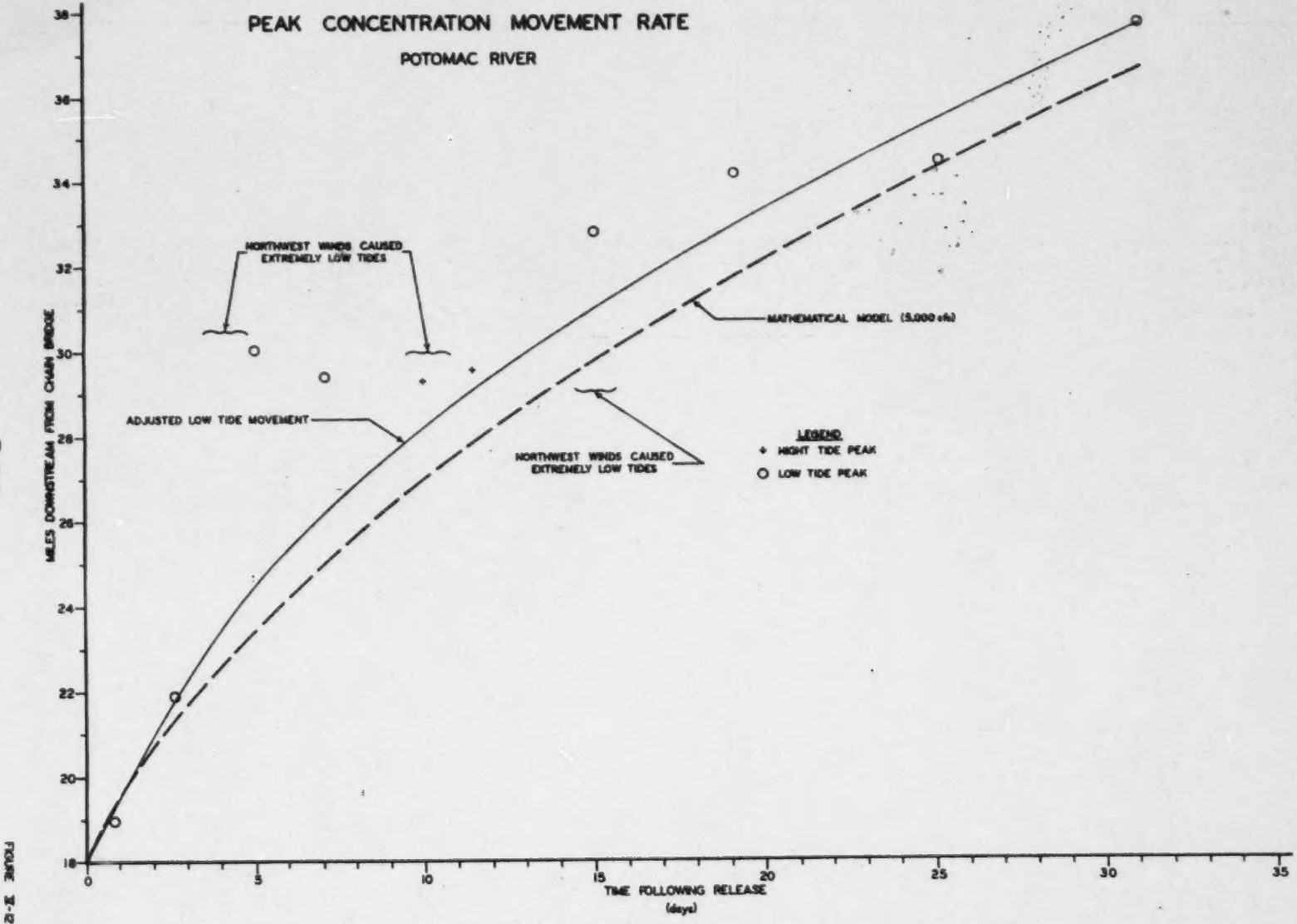


FIGURE 3-12

LOW WATER TIDAL HEIGHTS

WASHINGTON, D.C.

1969

DATUM = 4.26 ft. MLW

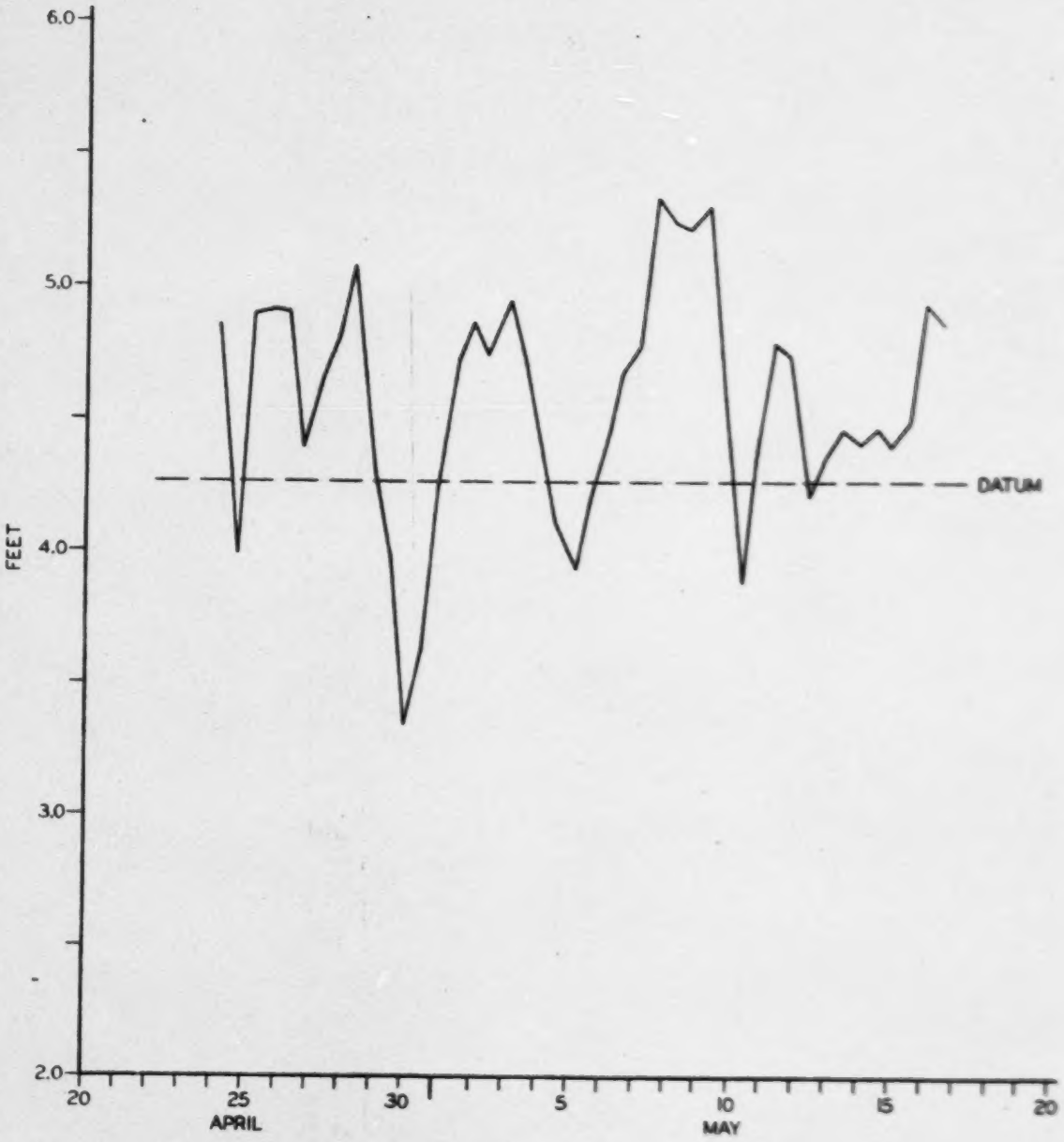


FIGURE II-13

from 0.76 to 2.17 as presented in Table V-2 and Figure V-14 shows close agreement with values determined by Hetling [3]. In the area near the Piscataway embayment, the dispersion coefficient was about 0.60 smpd.

Except for the May 7, 1969 data, the dispersion coefficient for the trailing edge of the release was higher than for the leading edge. This could possibly be due to shearing effects caused by differences in the cross-sectional velocities.

TABLE V-2

Dispersion Coefficient Summary

Potomac Estuary

Date	Days After Release	Dispersion Coefficient			Remarks
		Trailing (sq mi/day)	Leading (sq mi/day)	Average (sq mi/day)	
4-30-69	5.12	2.58	1.19	1.89	Extreme low tides
5-02-69	7.16	2.45	0.90	1.67	
5-05-69	10.16	2.60	1.30	1.95	
5-05-69	10.25	1.70	1.50	1.60	
5-07-69	12.08	0.22	1.29	0.76	Extreme high tides
5-10-69	15.12	1.50	1.03	1.26	
5-13-69	17.75	1.69	1.66	1.68	
5-14-69	19.13	2.33	2.01	2.17	
5-20-69	25.25	2.30	1.86	2.08	
5-26-69	31.50	1.84	1.19	1.51	Near background

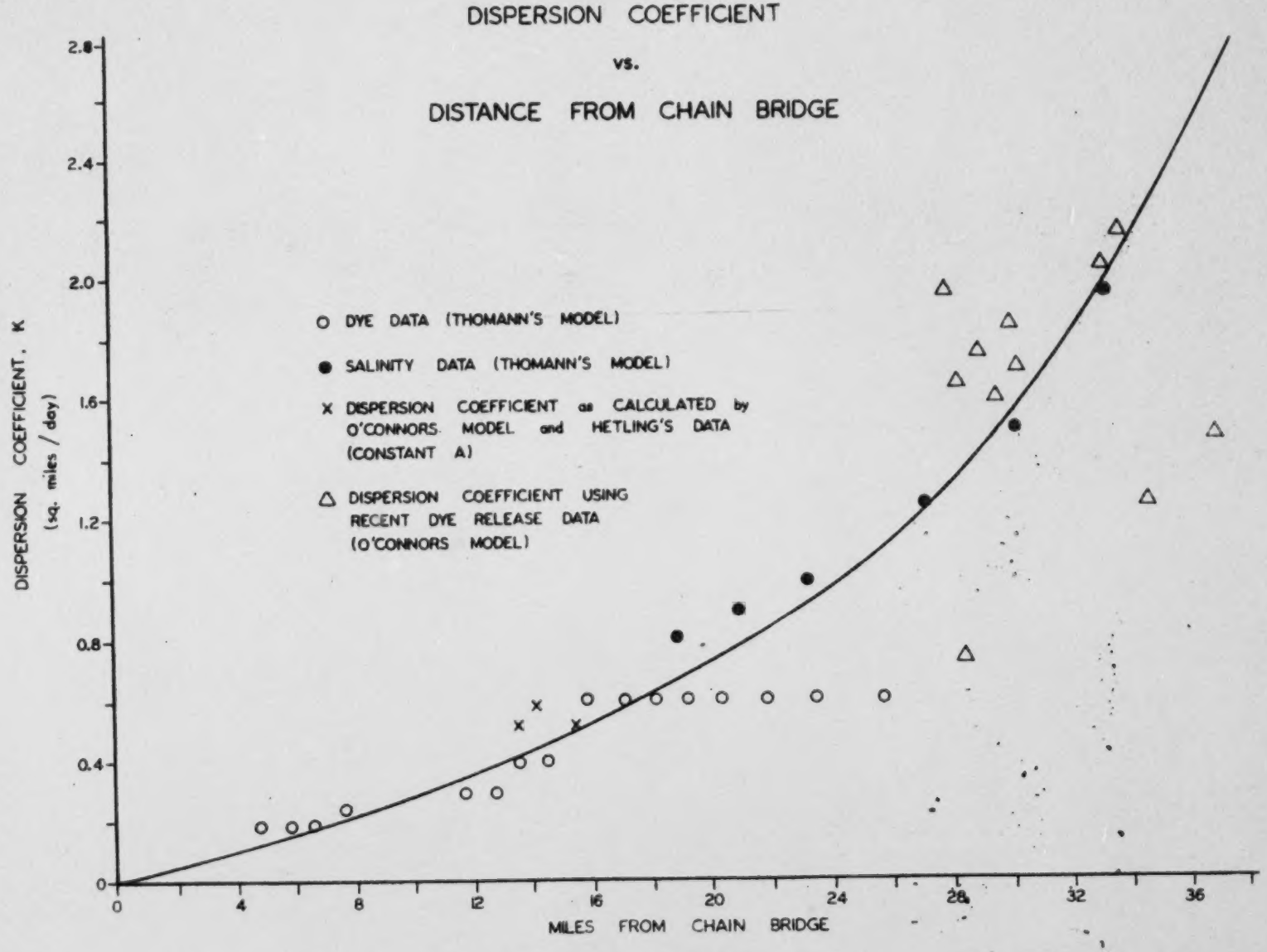

DISPERSION COEFFICIENT
vs.
DISTANCE FROM CHAIN BRIDGE
DISPERSION COEFFICIENT, K
(sq. miles / day)
MILES FROM CHAIN BRIDGE
O DYE DATA (THOMANN'S MODEL)
● SALINITY DATA (THOMANN'S MODEL)
X DISPERSION COEFFICIENT as CALCULATED by O'CONNORS MODEL and HETLING'S DATA (CONSTANT A)
△ DISPERSION COEFFICIENT USING RECENT DYE RELEASE DATA (O'CONNORS MODEL)
0
0.4
0.8
1.2
1.6
2.0
2.4
2.8
4
8
12
16
20
24
28
32
36

FIGURE IX-14

CHAPTER VI

PISCATAWAY EMBAYMENT DYE RELEASE

A Piscataway embayment dye release was made to simulate the movement of a wastewater discharge into the embayment. The results obtained were used to determine the feasibility of locating an outfall in the embayment.

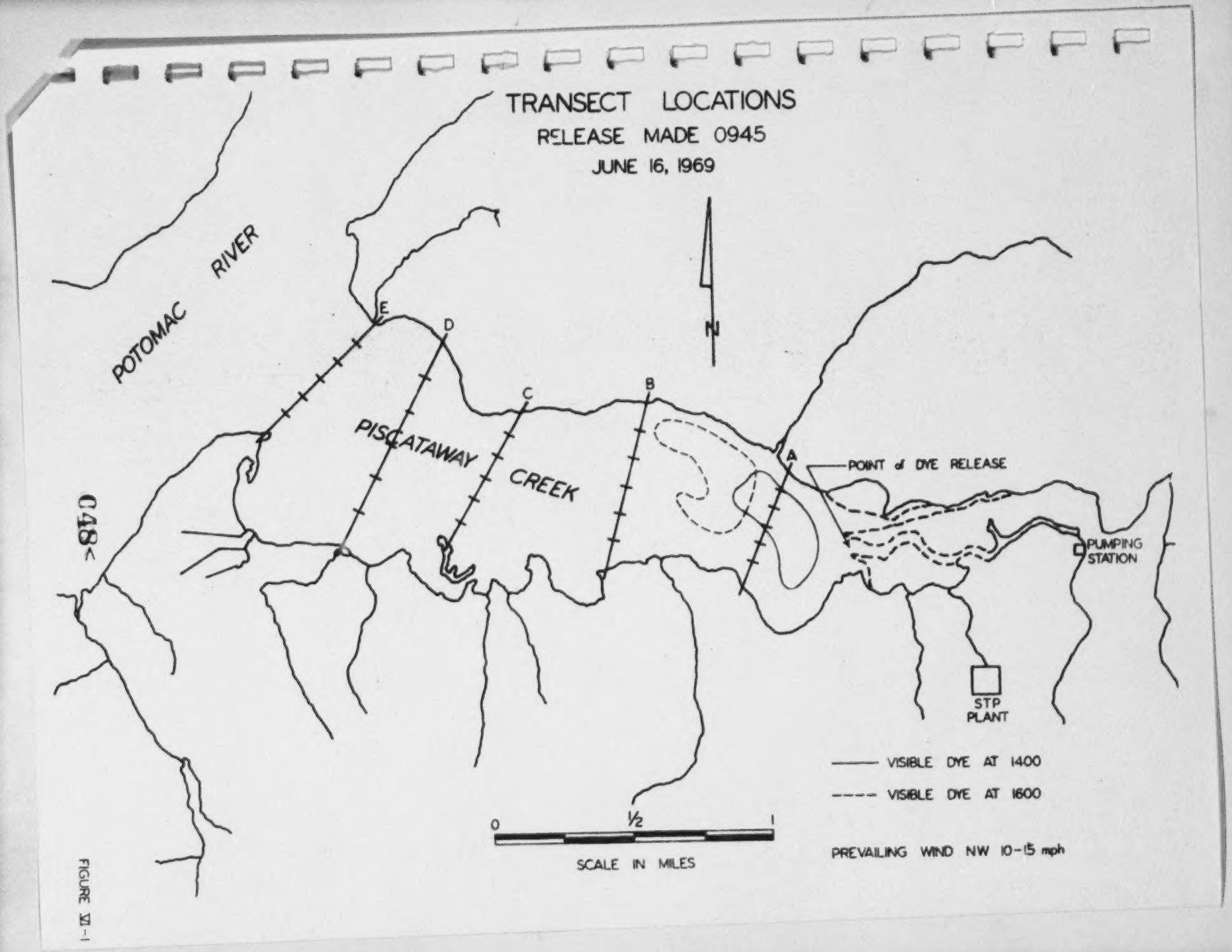
A. RELEASE CONDITIONS

At approximately midstream and 0.25 miles east of Transect A (Figure VI-1), 8 pounds of a 20 percent concentration of Rhodamine WT dye were released instantaneously at the surface. The release was made during high tide to simulate the maximum flow and mixing effect in the embayment. Tidal stages on June 16, 1969, the day of the release, were as follows:

High tide	9:26 a.m.
High slack water	10:10 a.m.
Time of dump	9:45 a.m.

B. TRANSECT LOCATIONS AND MONITORING SYSTEM

Samples were taken along each transect (Figure VI-1) during high and low water slack tides during the first day of the dye release. Samples were taken every day for the next four days and then twice a week until the measured dye concentrations decreased to approximately the background concentration before the release. Transect locations were chosen in such a manner as to demonstrate the effects of the embayment configuration and tidal flushing and to provide information describing the movement of the dye.


TRANSECT LOCATIONS
RELEASE MADE 0945
JUNE 16, 1969
POTOMAC RIVER
PISCATAWAY CREEK
E
D
C
B
A
N
POINT of DYE RELEASE
PUMPING STATION
STP PLANT
VISIBLE DYE AT 1400
VISIBLE DYE AT 1600
PREVAILING WIND NW 10-15 mph
0
1/2
1
SCALE IN MILES
FIGURE VI-1

C. ANALYSIS OF DYE RELEASE DATA

Figures VI-1 through VI-5 show that the movement of the dye was influenced by wind direction. Figure VI-1 indicates that the dye moved in the same direction as the prevailing wind on that day.

Figures VI-2 through VI-5 show that most of the dye remains in the same area indicating that the net tidal movement is very slight, in that section of the embayment. It took approximately three weeks for the dye to diffuse out of the embayment during which the concentration isopleth of the transect data indicated little evidence of mixing in the embayment.

The dispersion coefficient based upon the method outlined by O'Connor [5] was about 0.05 square miles per day. Because of the very low inflow from the tributary streams, the velocity of the fresh water inflow to the embayment was assumed to be zero.

The embayment can be divided into three distinct segments each having different characteristics. The first segment, extending from the most eastward point shown in Figure VI-1 to the end of the floral growth shown, has no significant mixing because of this growth. The upper segment is flushed only during heavy rains or extreme high tides.

The second or middle segment extends from the floral growth westward to Transect C. There is no significant mixing in this segment and only minimal tidal transport which occurs mainly at extremely high or low tides.

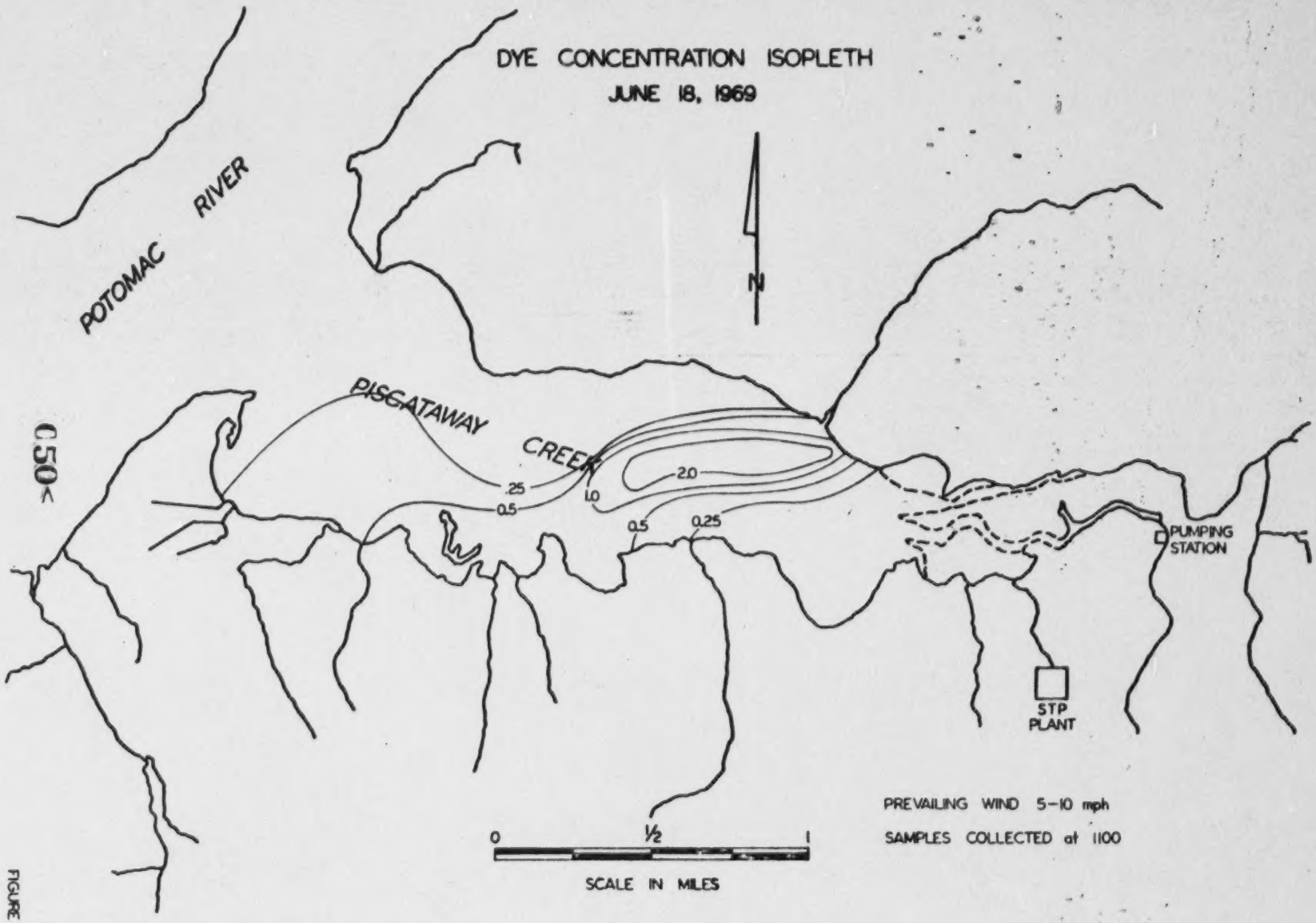
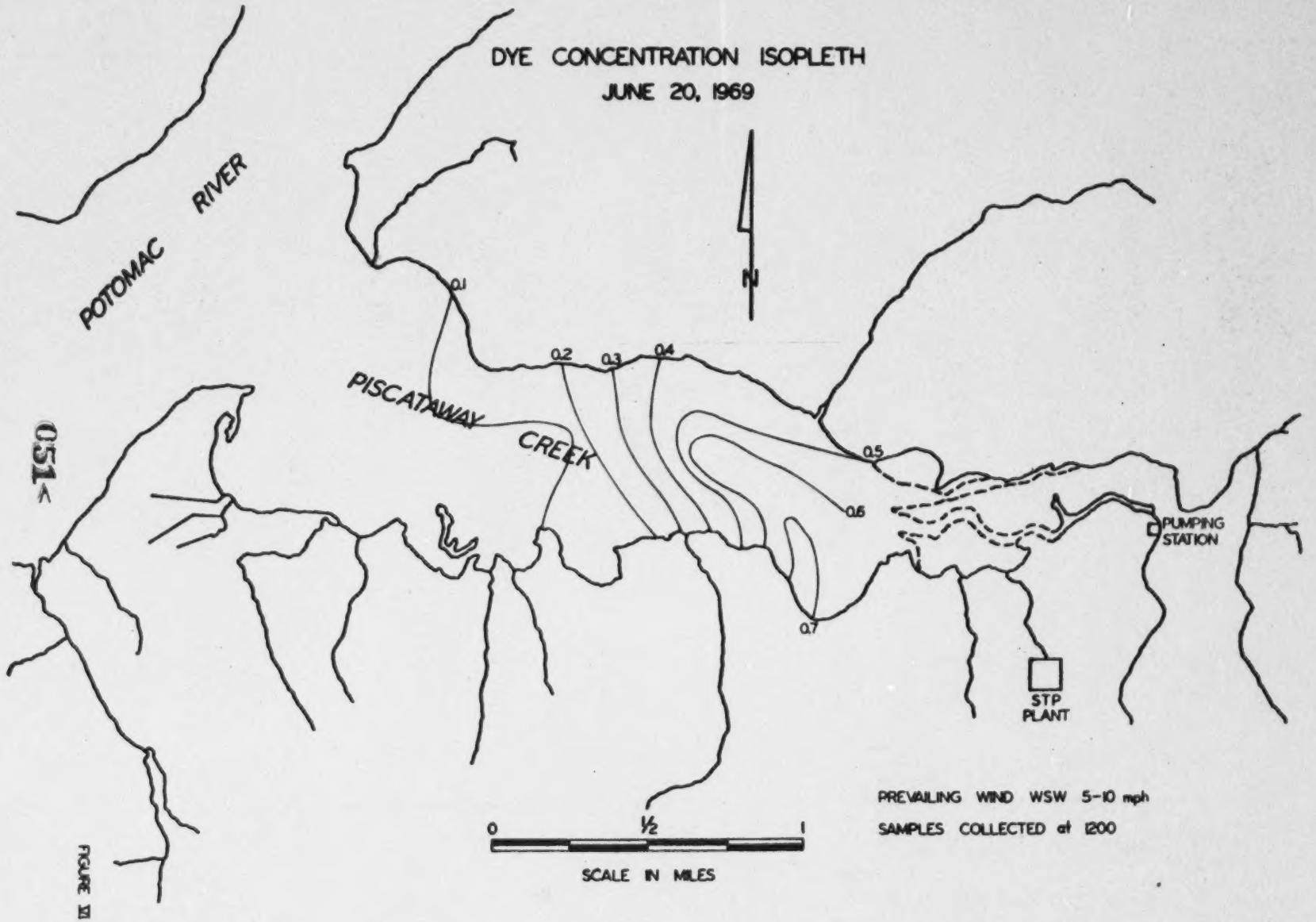

DYE CONCENTRATION ISOPLETH
JUNE 18, 1969
POTOMAC RIVER
N
PISCATAWAY CREEK
.50<
.25
.5
1.0
2.0
0.5
0.25
PUMPING STATION
STP PLANT
0
½
1
SCALE IN MILES
PREVAILING WIND 5-10 mph
SAMPLES COLLECTED at 1100

FIGURE VI-2



051

FIGURE XII-3

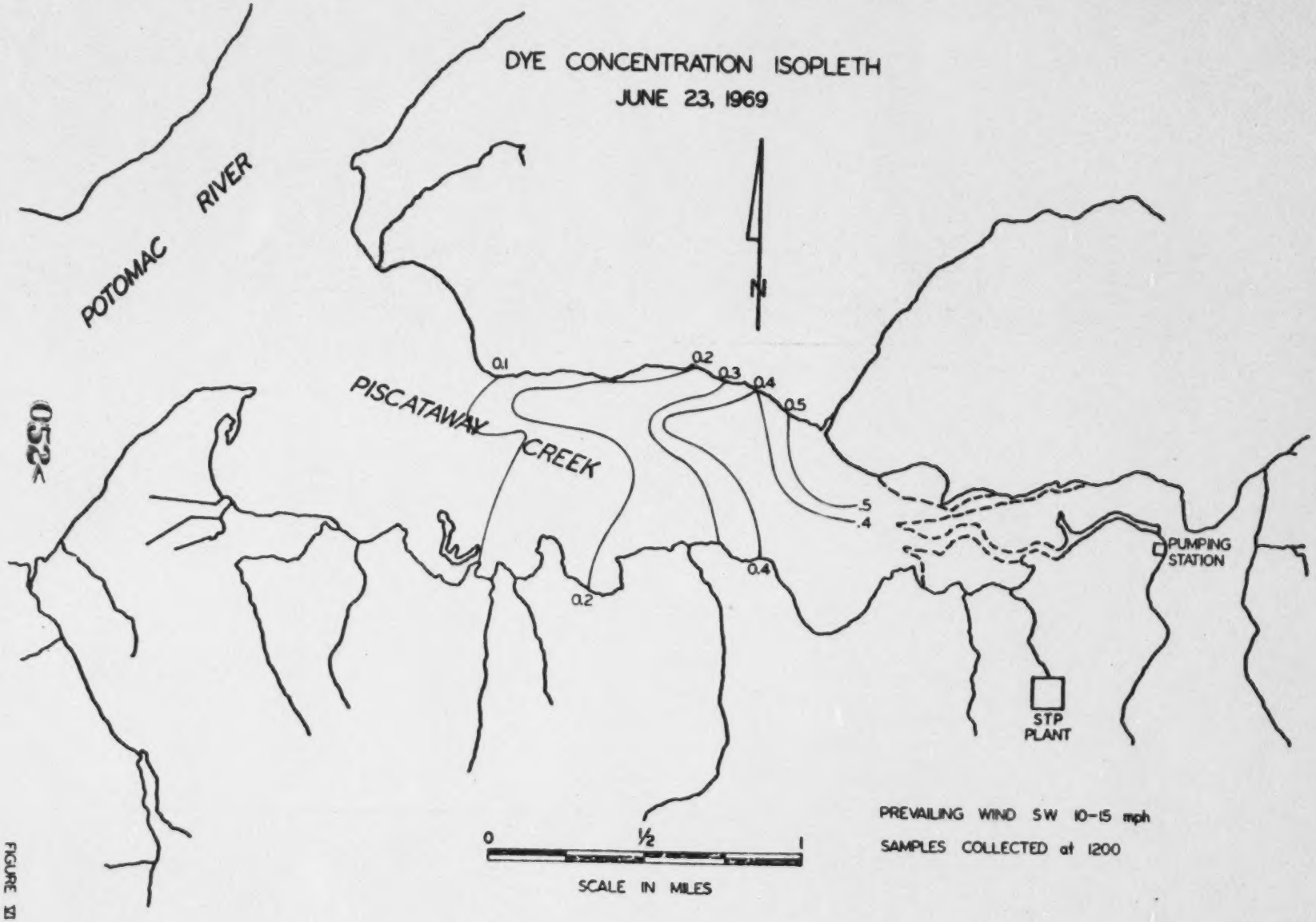
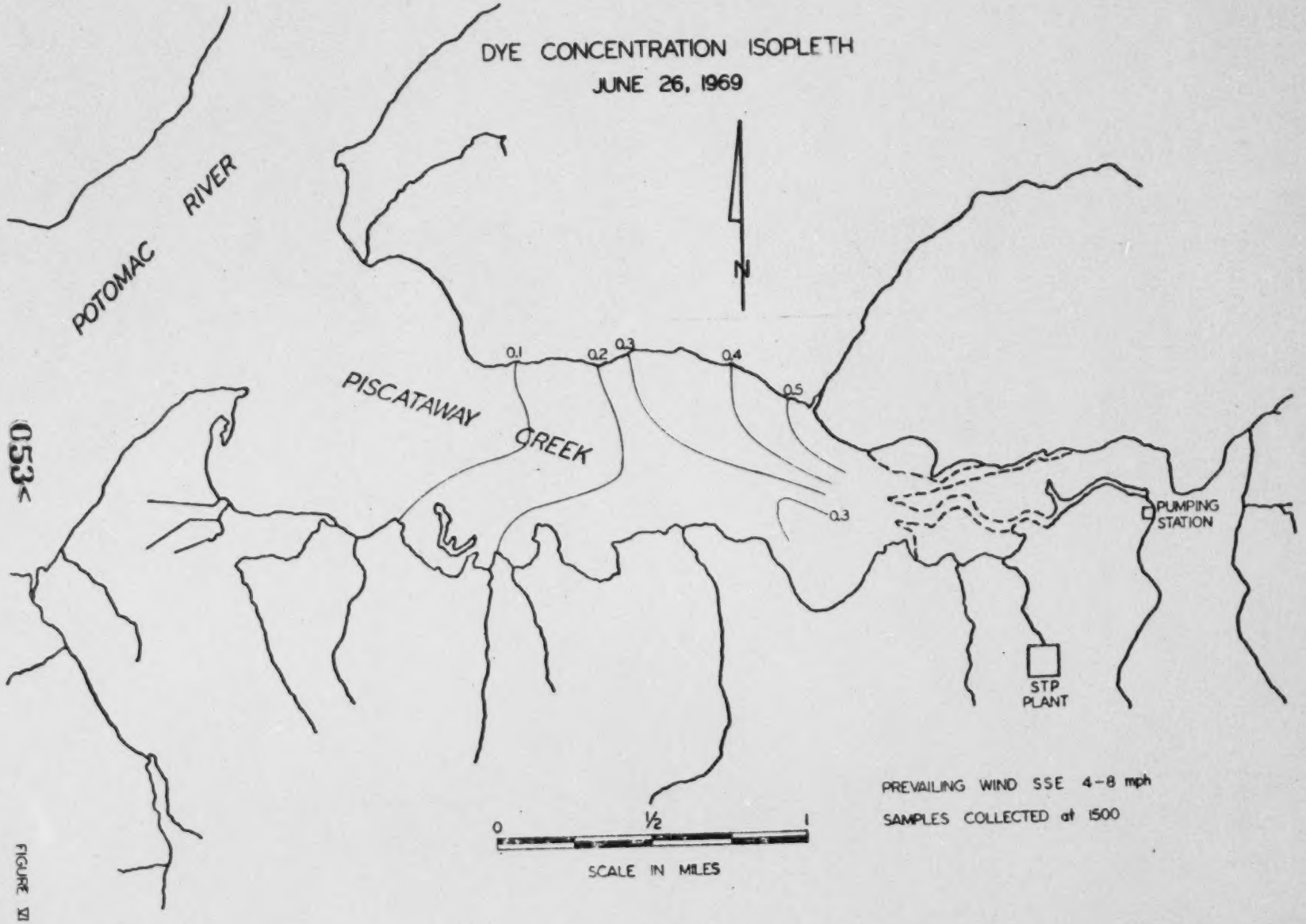

DYE CONCENTRATION ISOPLETH
JUNE 23, 1969
POTOMAC RIVER
PISCATAWAY CREEK
N
0.1
0.2
0.3
0.4
0.5
.5
.4
0.4
0.2
PUMPING STATION
STP PLANT
0
½
1
SCALE IN MILES
PREVAILING WIND SW 10-15 mph
SAMPLES COLLECTED at 1200

FIGURE XI-4



053

FIGURE XI - 5

The third segment extends from Transect C to the estuary and is marked by pronounced tidal transport from the Potomac Estuary. It is in this third segment that mixing and flushing occurs during each tidal cycle (Figures VI-2 and VI-5).

CHAPTER VII

ENGINEERING CONSIDERATIONS

In evaluating the location of the outfall, four engineering criteria were considered:

A. Dispersion,

B. Dilution and transport,

C. Intrusion into the numerous embayments, and

D. Time of travel.

These are discussed separately below:

A. DISPERSION

The dispersion coefficient is the parameter used in this report to indicate how rapidly a pollutant diffuses. Dispersion coefficients in the upper Potomac Estuary range from 0 to 3 smpd with a value of 0.66 smpd in the vicinity of the proposed outfall.

The Piscataway embayment has an average dispersion coefficient of 0.05 smpd. Based upon the dispersion coefficient, the lower value in the embayment indicates that it is advantageous to discharge the effluent into the main stem of the Potomac.

As shown in Figure V-6, the dispersion coefficient increases exponentially with distance from Chain Bridge. Consequently, considering dispersion only, it is more advantageous to locate the outfall as far downstream as possible.

B. DILUTION AND TRANSPORT

1. Discharge into Main Stem of Potomac

Figure VII-1, which is based on numerous mathematical model runs, indicates that there is no particular advantage in locating an outfall in either Segment 9, 10, or 11 (Figure III-1 gives the estuary segments). The effects of dilution and dispersion in each of the segments are the same (Table VII-1 gives segment volumes).

There would be a slight advantage in locating the outfall in Segment 11 as far downstream as possible from the large loading in Section 6 which is from the Washington, D.C. metropolitan area. However, the projected population discharging into Section 12 from the Gunston Cove area in Virginia is expected to be about 310,000 in 1980 and over 1,600,000 by 2020 and must be considered as well as the future loading from the Piscataway area in Maryland. Hence, if the proposed outfall were located in Segment 11, it would result in a combined population of over 2,000,000 by 2020 from Maryland and Virginia discharging wastewater into Segments 11 and 12.

2. Discharge into Piscataway Embayment

Stream survey data as reported in 1968 [8] and as summarized for 1969 in Figures VII-2, VII-3, VII-4, and VII-5 also indicated that the water quality in the embayment near the Potomac Estuary is controlled by the quality in the Potomac. In the upper end

Table VII-1

POTOMAC ESTUARY PHYSICAL PARAMETERS

Segment	Length (Miles)	Volume* (Cubic Feet) x 10^7	Surface Area (Square Feet) x 10^6	Mean* Depth (feet)
1	2.69	25	8.3	30.1
2	2.09	24	14.3	16.7
3	1.75	33	26.4	12.5
4	1.31	40	40.0	10.0
5	1.87	45	33.8	13.3
6	2.11	52	46.4	11.2
7	2.57	76	93.4	8.1
8	2.19	66	63.9	10.3
9	2.44	79	85.0	9.3
10	2.06	65	60.8	10.7
11	2.25	92	78.3	11.7
12	3.95	252	219.7	11.5
13	2.94	170	124.1	13.7
14	2.93	250	201.7	12.4
15	4.41	330	301.9	10.9
16	4.26	445	314.3	14.1
17	4.42	520	368.6	14.1
18	4.57	535	428.5	12.5
19	5.36	620	131.4	26.7
20	5.20	525	334.5	15.7
21	5.69	630	387.2	16.3

* Mean Tide Level

of the embayment, the water quality is mainly under the influence of the discharge from the Piscataway wastewater treatment facility.

Because of the slow diffusion process, the concentration of nutrients was consistently higher in the upper part of the embayment as exhibited in Figures VII-2 and VII-3. Because of the high concentration of algal cells as indicated by chlorophyll a (Figure VII-4), the DO (Figure VII-5) was also higher in the upper portion. These data were for daylight conditions only. The reduction in all four parameters in August 1969 was due to a flushing action caused by heavy rains.

Simulated profiles for a discharge into the upper end of the embayment, presented in Figure VII-6, verify this slow diffusion process and also show the effect of various decay rates and wastewater flows on the concentration of a pollutant. It also can be seen that major effects of the discharge were in the upper and middle portion of the embayment near the discharge point.

When the profiles in Figure VII-1 are compared to Figure VII-6, it can readily be observed that the capacity to receive and transport nutrients for given residuals in the receiving water is about 100-fold greater in the main Potomac than in the embayment. For example, a discharge of 100,000 lbs/day will increase the concentration about 1.5 mg/l in the main Potomac while only 1,000 lbs/day will increase the concentration in the upper embayment to about the same level.

SIMULATED POLLUTANT PROFILES

POTOMAC RIVER ESTUARY

DISCHARGES of 100,000 lbs./day
into MODEL SECTIONS 9, 10, and 11

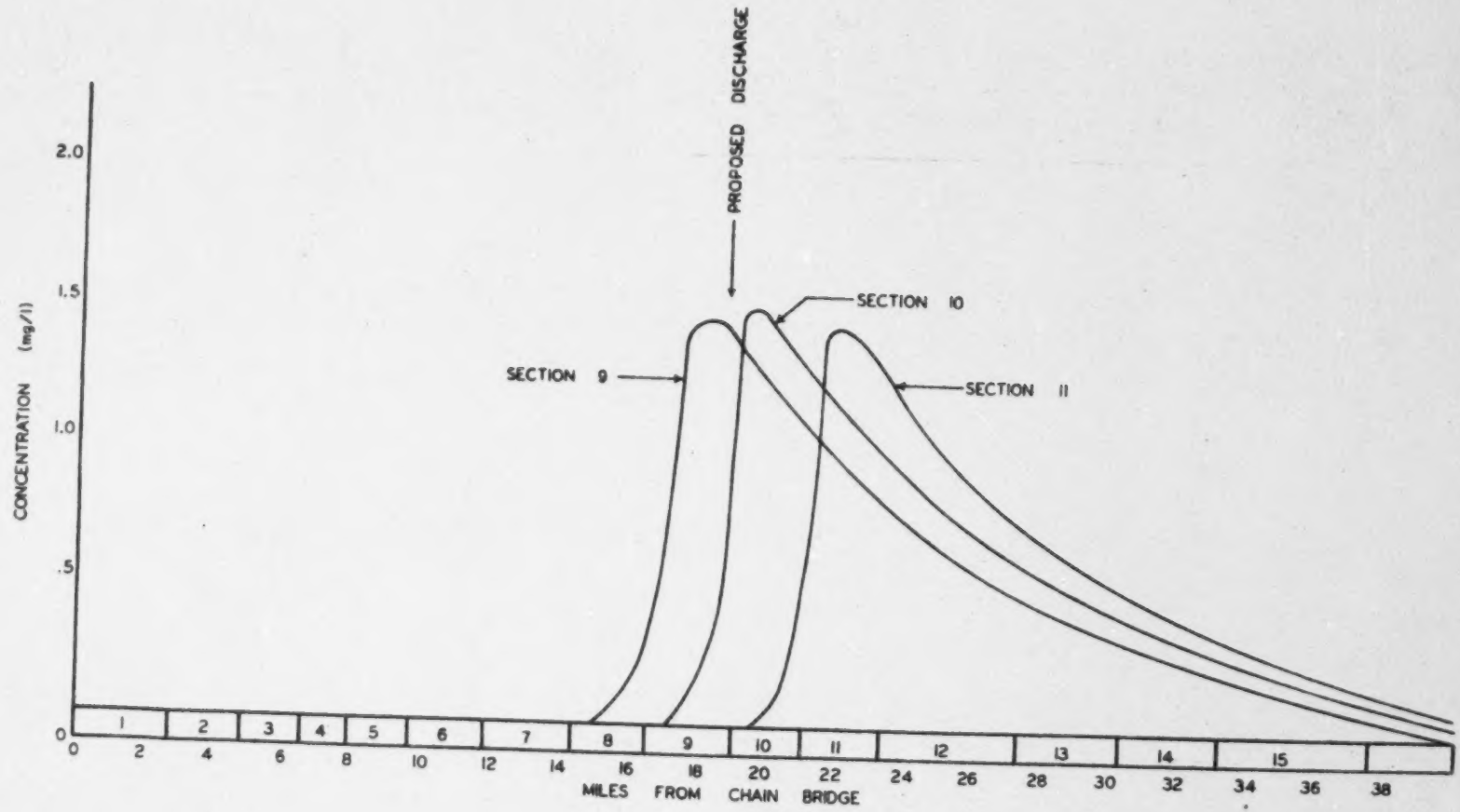


FIGURE III - 1

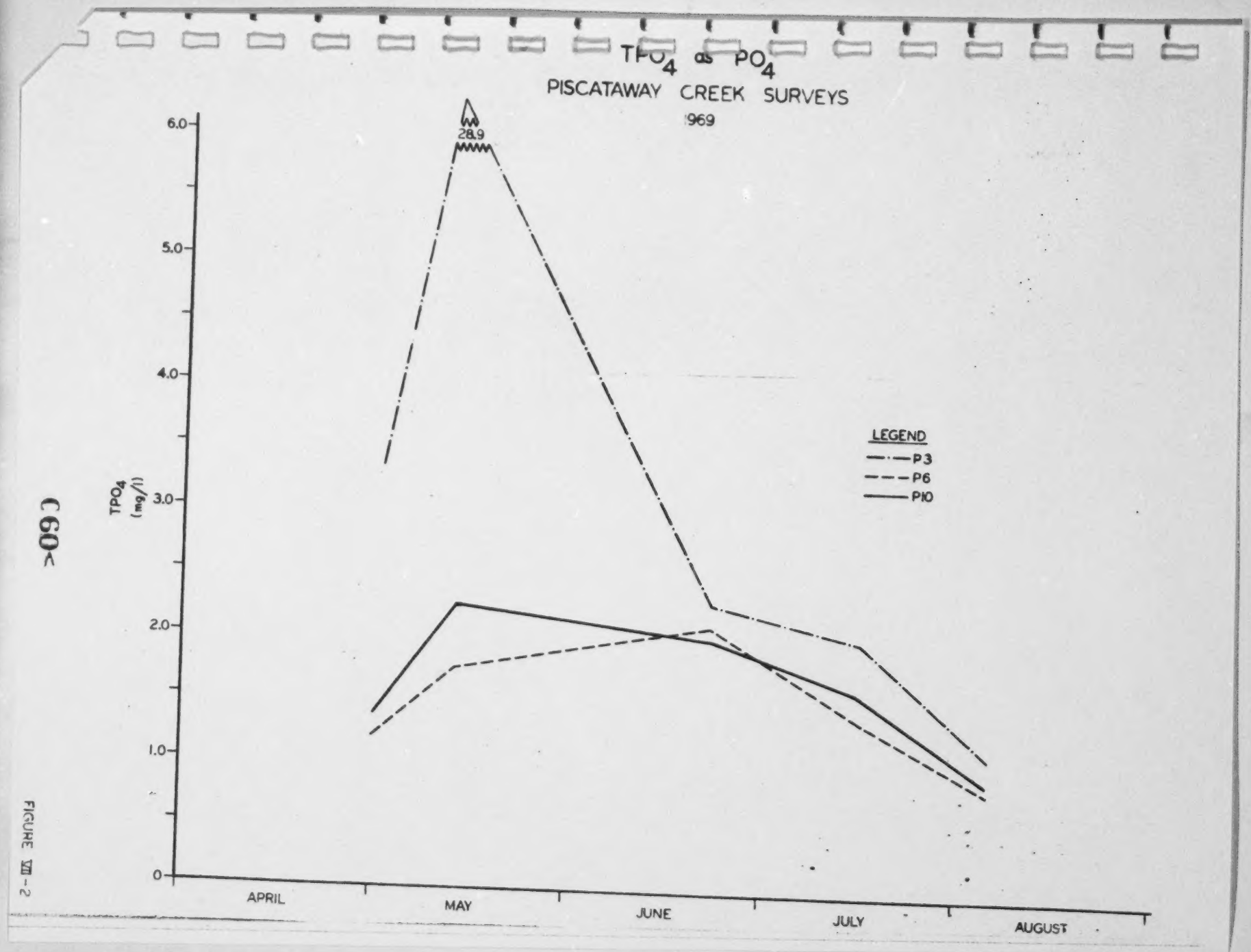

TPO4 as PO4
PISCATAWAY CREEK SURVEYS
1969
28.9
6.0
5.0
4.0
3.0
2.0
1.0
0
TPO4 (mg/l)
LEGEND
P3
P6
P10
APRIL
MAY
JUNE
JULY
AUGUST

FIGURE VII-2

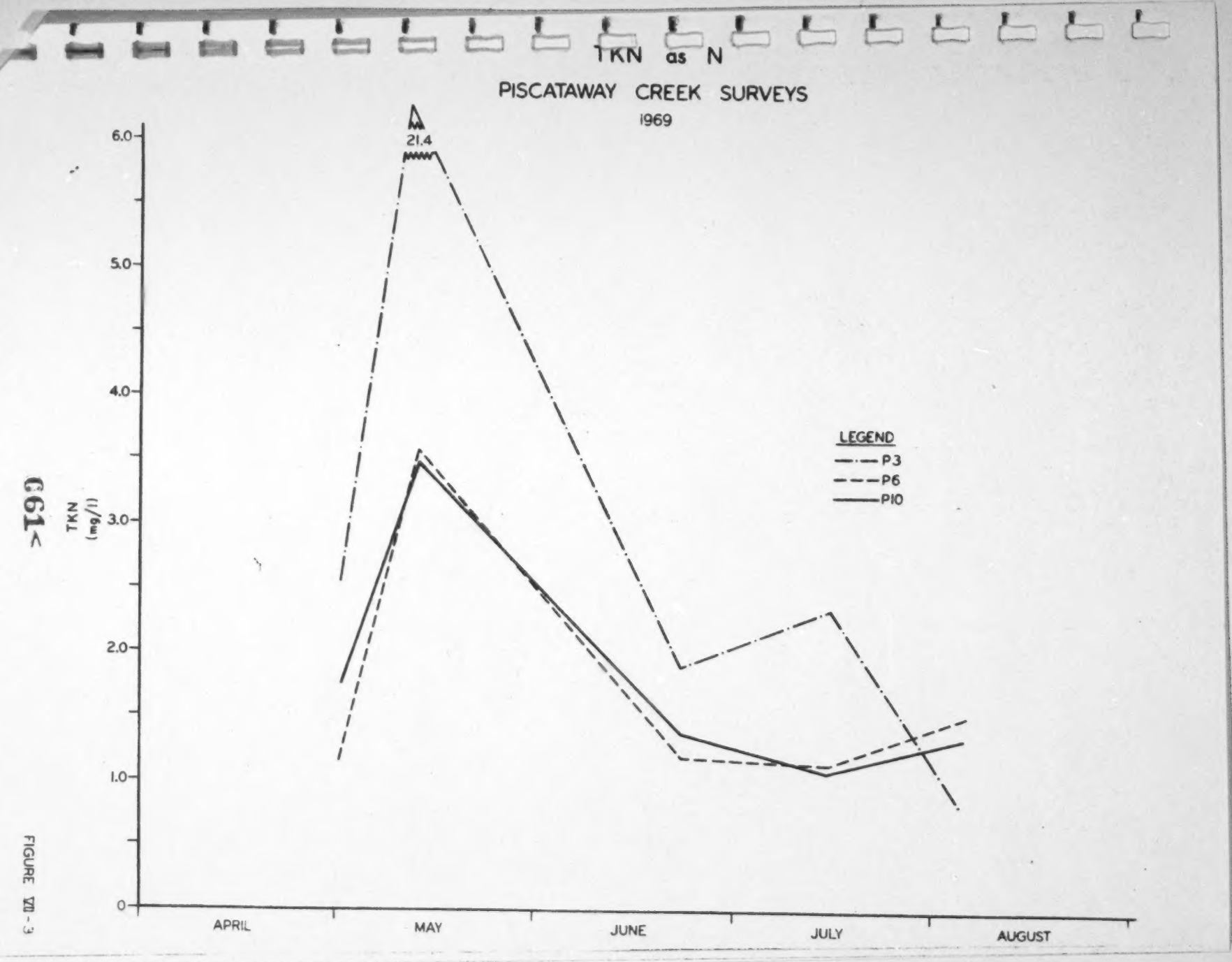

TKN as N
PISCATAWAY CREEK SURVEYS
1969
21.4
6.0
5.0
4.0
3.0
2.0
1.0
0
TKN (mg/l)
LEGEND
P3
P6
P10
APRIL
MAY
JUNE
JULY
AUGUST

FIGURE VII - 3

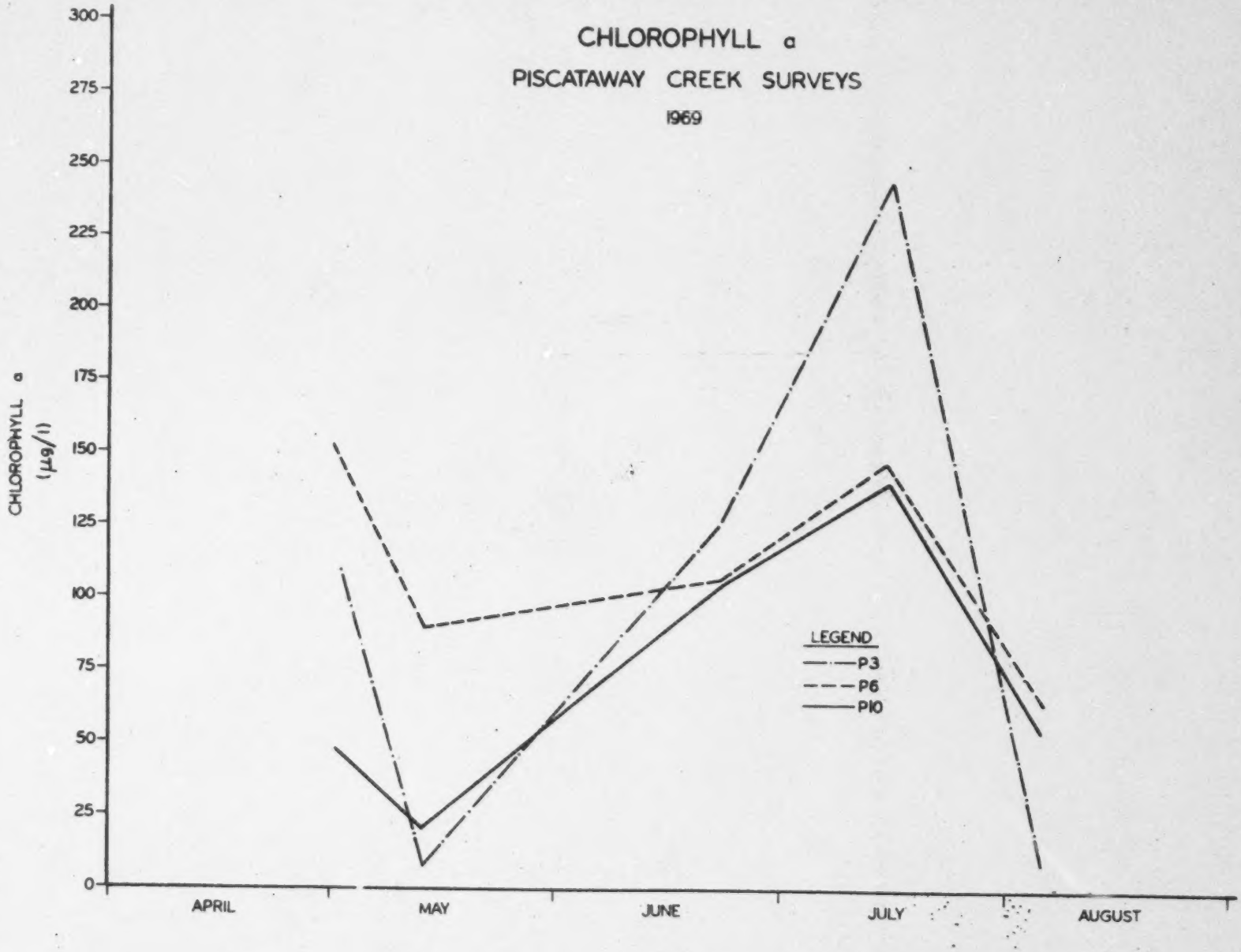

CHLOROPHYLL a
PISCATAWAY CREEK SURVEYS
1969
CHLOROPHYLL a (µg/l)
300
275
250
225
200
175
150
125
100
75
50
25
0
APRIL
MAY
JUNE
JULY
AUGUST
LEGEND
P3
P6
P10

FIGURE VII-4

DO

PISCATAWAY CREEK SURVEYS

1969

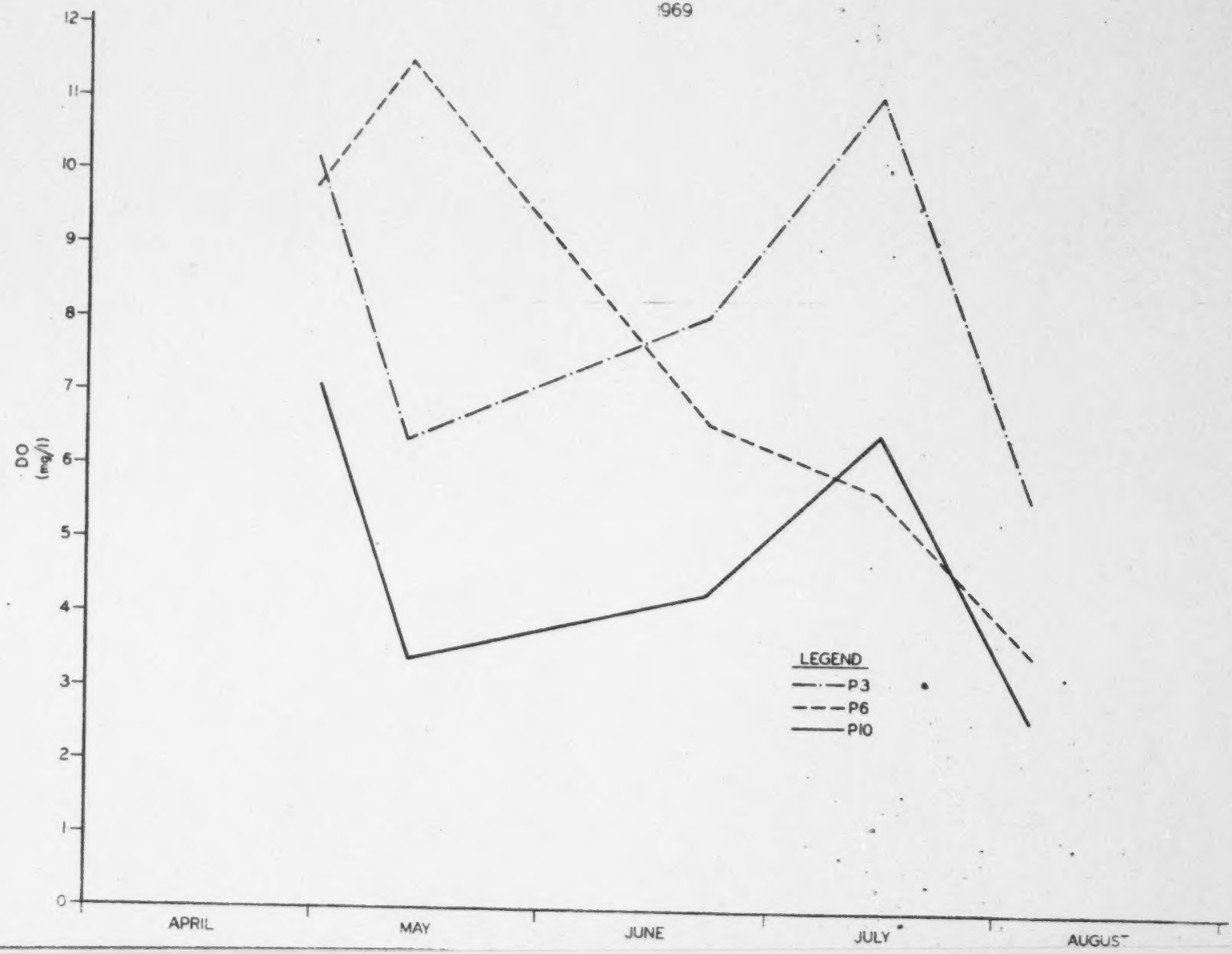


FIGURE VII-5

SIMULATED POLLUTANT PROFILES

PISCATAWAY EMBAYMENT

FOR DISCHARGES OF 1000 lbs./day

INTO EMBAYMENT AT MILES 1.87

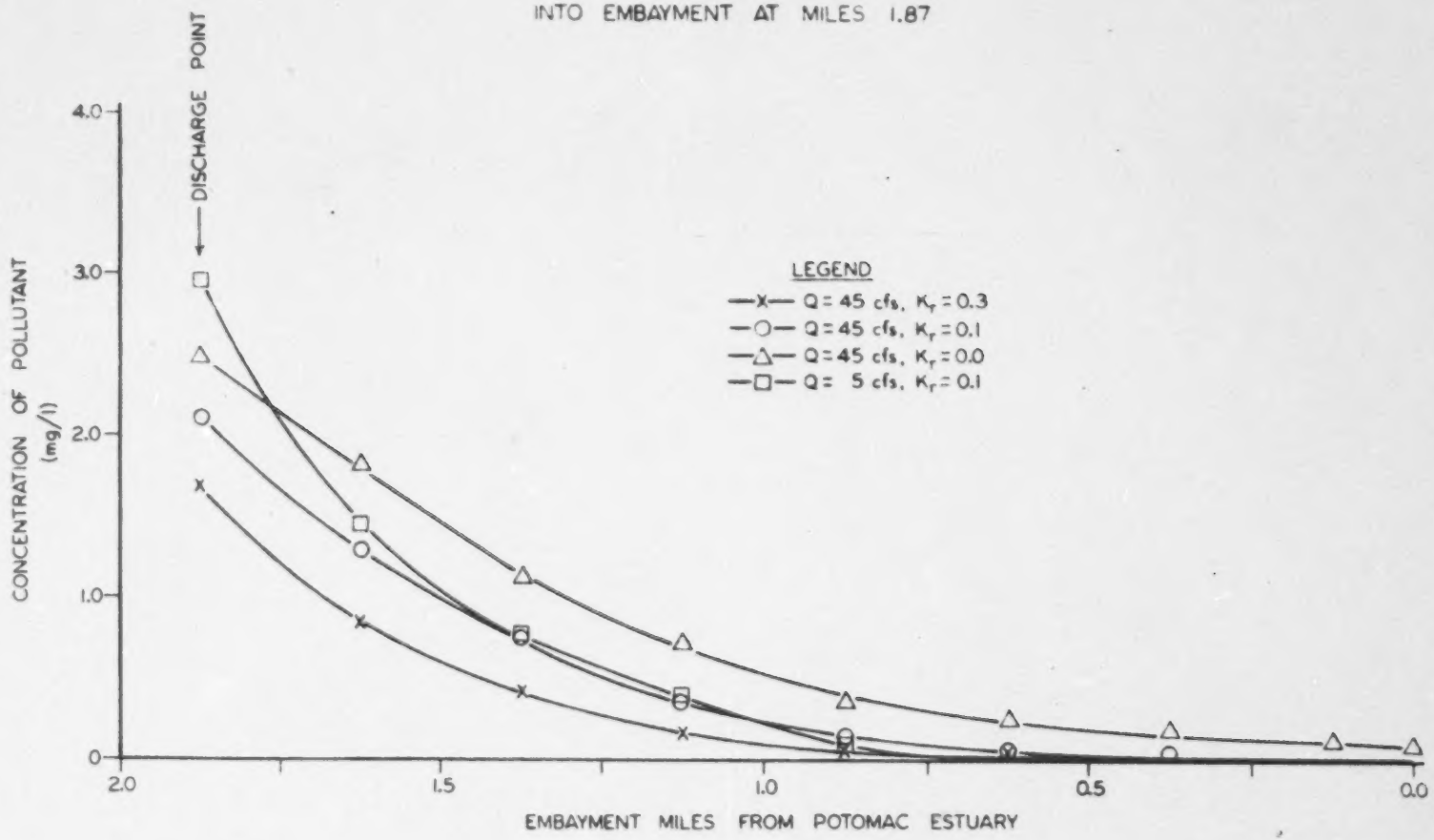


FIGURE III-6

Assuming the wastewater treatment requirements are met for discharges into the main Potomac, the maximum loading of total phosphorus to the embayment would be 50 lbs/day with total nitrogen being 250 lbs/day. This is based on maintaining a maximum increase in concentration of 0.1 mg/l of phosphorus and 0.5 mg/l of total nitrogen in the upper part of the embayment.

When the waste flow of about 5.0 mgd to the Piscataway facility is increased to 15 mgd as currently being planned, the treatment requirements as stipulated by the conferees at the May 1969 Potomac River Enforcement Conference will result in phosphorus concentrations within these limits. The concentration of nitrogen will be slightly above the recommended maximum of 0.5 mg/l. If the plant's capacity is expanded above 15 mgd, a higher degree of treatment than that stipulated at the Enforcement Conference would be required if the maximum phosphorus and nitrogen limits are to be met. Table VII-2 gives projected loadings before and after treatment.

Table VII-2

NUTRIENT LOADINGS

For Various Flow From The
Piscataway Wastewater Treatment Facility

	Before Treatment*		After Treatment**	
Flow (mgd)	TPO_4 as P (lbs/day)	T. Nitrogen (lbs/day)	TPO_4 as P (lbs/day)	T. Nitrogen (lbs/day)
5	460	840	18	126
15	1,380	2,500	54	378
30	2,760	5,040	110	756
100	4,600	8,400	184	1,260

* Based on average concentration of TPO_4 of 11.0 mg/l and 22 mg/l of total nitrogen.

** Based on Potomac Enforcement Conference report of 96 percent removal of phosphorus and 85 percent removal of nitrogen.

C. INTRUSION INTO EMBAYMENTS

Direct intrusion into Swan Creek and the Piscataway embayment was observed visually after the surface release. This consisted of a "slug" of dye that hugged the Maryland side of the Potomac Estuary from the proposed outfall location to Swan Creek.

A horseshoe configuration of dye was formed in the Piscataway embayment indicating the upper range of tidal intrusion therein. In Swan Creek a wedge-like intrusion was observed initially and later a horseshoe configuration. Direct intrusion into Swan Creek could possibly be eliminated by moving the outfall downstream, but direct intrusion into the Piscataway embayment and hugging along the shore of the Fort Washington Park would still occur.

The subsurface release gave no indication of direct intrusion in "slug" concentrations into any of the embayments. Neither did the subsurface release give any indication of hugging the park shoreline.

While placement of the proposed outfall in the main channel at a depth of about 40 feet will eliminate direct intrusion into the embayments, it will not eliminate intrusion caused by tidal exchanges after mixing. Moreover, since there are numerous embayments along the Potomac Estuary, tidal intrusion into an embayment will always occur to some degree.

D. TIME OF TRAVEL

Oyster harvesting is one of Maryland's leading seafood industries. The effects of the pollutants in the effluent on oyster production is beyond the scope of this report. Consideration was given to an outfall location that would yield the longest time of travel for biologically degradable pollutants and coliforms originating in wastewater discharges in the Washington area. The longer the travel time the more "buffer zone" is provided and thus any adverse effect on the oyster beds, located about 64 miles below Chain Bridge, will be minimized.

For a freshwater inflow of about 5,000 cfs, the advection velocity in the Potomac Estuary in the region of the Piscataway embayment is 1.4 mi/day and decreases to 0.5 mi/day at Mile Point 30. The travel time from the proposed outfall to the oyster beds is about 84 days at a flow of 5,000 cfs. This travel time would be reduced to 72 days if the outfall were at Indian Head. Travel time for other flows are given in Figure VII-7.

The best possible outfall location, considering the time of travel of the pollutant, would be at the most upstream position. This would allow the maximum time for decay of any biological pollutant, including coliforms, before it reaches the oyster beds.

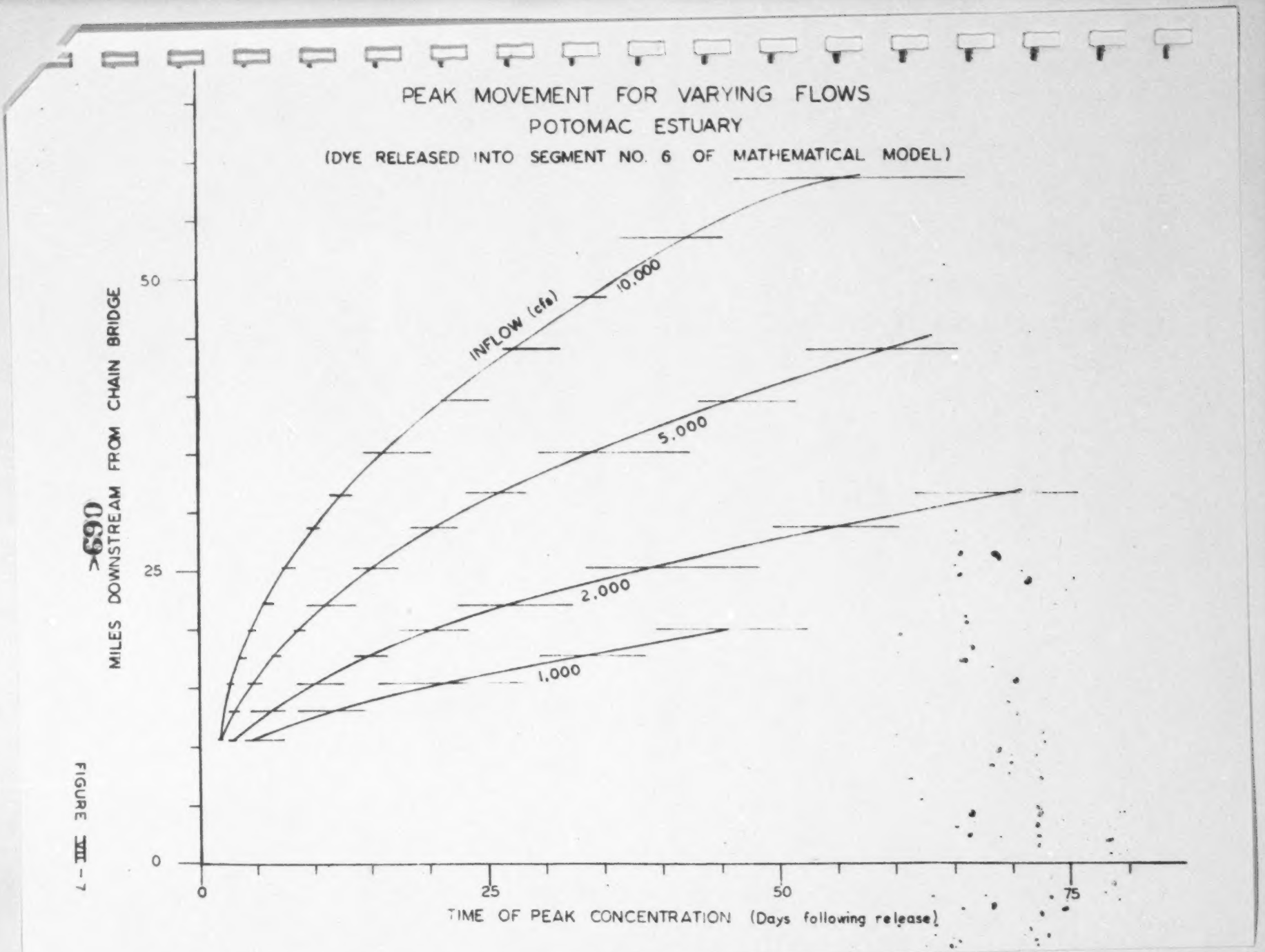

PEAK MOVEMENT FOR VARYING FLOWS
POTOMAC ESTUARY
(DYE RELEASED INTO SEGMENT NO. 6 OF MATHEMATICAL MODEL)
INFLOW (cfs)
10,000
5,000
2,000
1,000
MILES DOWNSTREAM FROM CHAIN BRIDGE
>690
50
25
0
0
25
50
75
TIME OF PEAK CONCENTRATION (Days following release)

FIGURE III - 7

E. DISCUSSION OF CONSIDERATIONS

The two basic alternatives in locating the outfall from the Piscataway wastewater facility are (1) advanced wastewater treatment with discharge into the main Potomac, and (2) a higher degree of advanced wastewater treatment with discharge into Piscataway embayment. Dye studies and simulation analyses from mathematical models indicate that the most advantageous location of the outfall is into the main channel of the Potomac in the vicinity of the proposed outfall. Based on the subsurface dye released, it appears that if the outfall is extended out into the main channel where the depth of water is over 40 feet, maximum transport and minimum embayment intrusion would occur.

During the course of this study, it also has been pointed out that if a sufficient level of treatment is provided with a given plant reliability, wastewater can be discharged at any point in the system. Nevertheless, with ever increasing need for protecting the water quality and with the current state of waste treatment technology, the most advantageous discharge point is the main channel of the Potomac estaury and not the present discharge point.

APPENDIX A

A. MATHEMATICAL MODELS

During the past 50 years, engineers and scientists have investigated the use of mathematical models to simulate the response of natural phenomena to varied conditions. Recently, with the development of computers, the use of such models has become feasible.

Mathematical models are useful tools in determining the distribution and resulting effect on water quality of conservative and non-conservative substances discharged into the receiving waters.

O'Connor [6] and Thomann [7] have developed mathematical models to simulate the effects of pollutants on the water quality in estuaries. O'Connor's model is based primarily on the conservation of mass, and for a one-dimensional estuary is as follows:

$$\frac{\partial c}{\partial t} = \frac{1}{A} \frac{\partial}{\partial r} \left[A \frac{\partial c}{\partial r} \right] - \frac{\partial c}{\partial r} \pm S_{(c,r,t)} \qquad (1)$$

where:

A = Cross-sectional area

c = Concentration of the substance

E = Dispersion coefficient

r = Distance from point of release

S = Sinks and sources

t = Time in days

u = Velocity

The variable c may apply to any substance. In this report, c is dye concentration.

In most estuaries, the cross-sectional area is a function of distance and can be related to distance by one of the following expressions as suggested by O'Connor [6]:

$$A = Ao\, e^{r} \qquad (2)$$

$$A = Ao\, (\frac{r}{ro}) \qquad (3)$$

$$A = Ao\, (\frac{r}{ro})^{n} \qquad (4)$$

The upper Potomac Estuary appears to be best described by a power function of the form of equation 4, as shown in Figure A-1.

An analytical solution to equation 1 is not available for the particular case of the Potomac Estuary. Therefore, a constant cross-sectional area was assumed and the following solution was obtained using O'Connor's model for an instantaneous release:

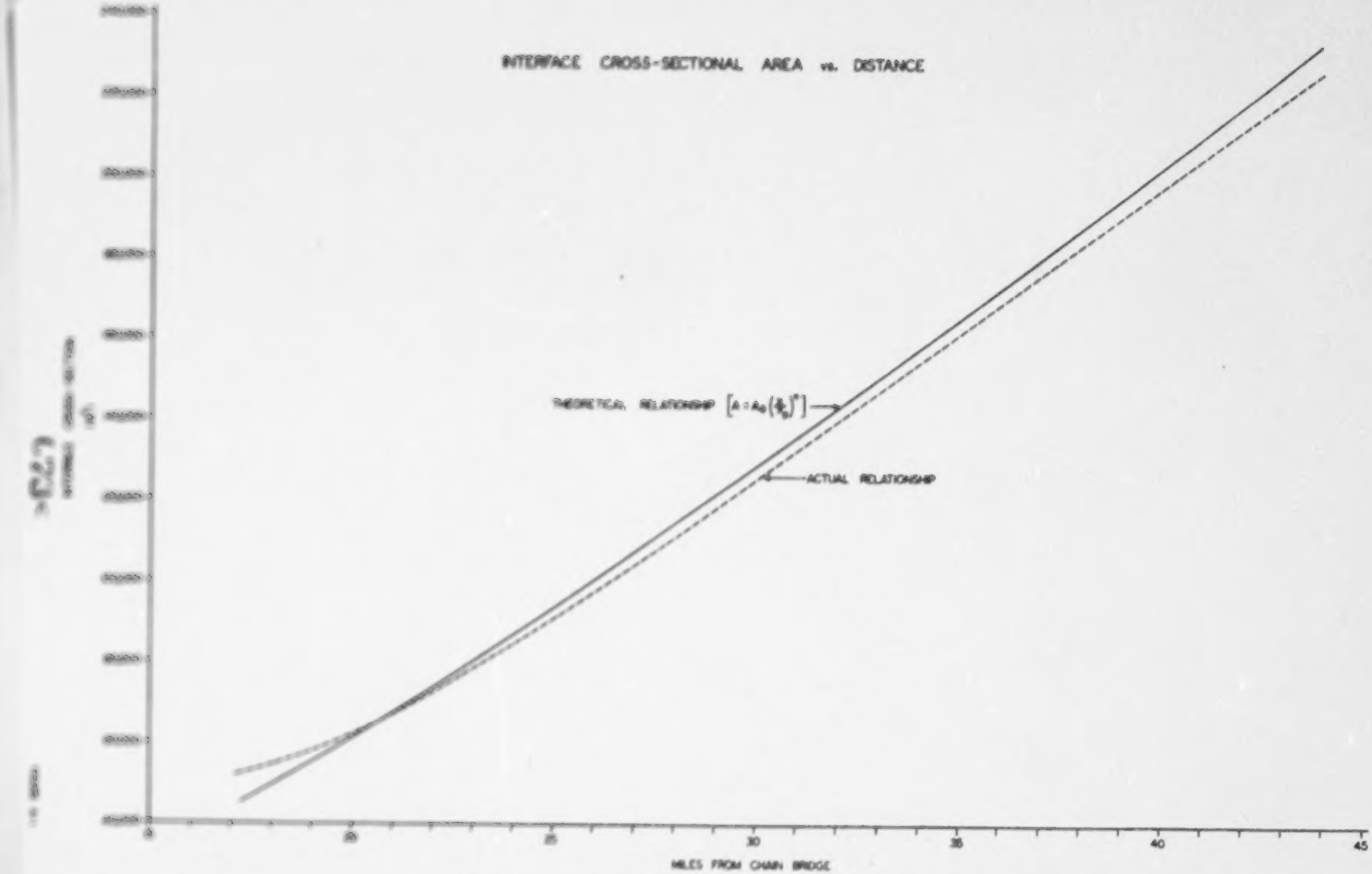
$$C = \frac{M}{2A\sqrt{\pi t^{n}}}\, e^{-\left(\frac{(r-ut)^{2}}{4Et} - kt\right)} \qquad (5)$$

where:

M = mass of dye released

k = 1st order decay rate with r, u, t, E as defined previously

The dispersion coefficient, which is the only unknown value in the above equation, can be directly related to the cross-sectional area as suggested by O'Connor [6].


INTERFACE CROSS-SECTIONAL AREA vs. DISTANCE
THEORETICAL RELATIONSHIP
ACTUAL RELATIONSHIP
0
10
15
30
35
40
45
MILES FROM CHAIN BRIDGE

Thomann found some advantage in a numerical solution, which today is applicable through the use of high speed digital and analog computers. In Thomann's model, a mass balance of a substance in each of a system of "n" segments, shown in Figure II-1, includes terms describing changes in dye concentration caused by advection, dispersion, and losses. A mass balance constituted for the "i" th segment takes the following form:

$$V_i \frac{dC_i}{dt} = Q_i \left(\xi_i C_i - 1 + (1 - \xi_i)C_i\right) - Q_i + \left(\xi_i + C_i + (1 - \xi_i + 1) C_i + 1\right) + E_i \left(C_i - 1^{-} C_i\right) + E_i + 1 \left(C_i + 1 - C_i\right) - dV_i C_i + P_i \qquad (6)$$

where:

V_i = Volume of "i" th segment (cf)

C_i = Mean dye concentration in "i" th segment (lb/cf)

Q_i = Net waterflow across the upstream boundary of the "i" th segment (cf/day)

= A dimensionless proportionality factor used to estimate the concentration at the upper boundary of the "i" th segment

E_i = Turbulent exchange factor for upstream boundary of the "i" th segment (cf/day)

d = Dye loss rate constant (day^{-1})

P_i = Rate of dye added from external sources (lbs/day)

t = Time (days)

There exist 20 linear first order, non-homogeneous, ordinary differential equations which were solved simultaneously by numerical

methods using a digital computer. The only value in the 28 equations which was not known was the turbulent exchange factor which was determined by use of Fick's first law of difussion; i.e.,

$$Ni\ (lb/sf/day) = K\ dC/dr\ (k\ dc/dr) \qquad (7)$$

where:

"N" is rate of mass transfer of substance per unit area across a boundary and "K" is the longitudinal dispersion coefficient. Thomann's disprsion coefficient is the same as the one described in the mathematical model by O'Connor.

The dispersion coefficient as described by both models is the unit square miles per day and is an indication of the ability of the receiving wate to diffuse the polluting substance. Values of "K" for the Potoma Estuary using Thomann's mathematical model as determined by Hetlig [3] for a dye release in May, 1965, range from zero at LittleFalls to 10 in the lower Potomac near the Chesapeake Bay. The dispersion coefficient used in the models is an average over the tidalcycle.

As mentiond previously, Thomann's mathematical model makes use of Fick's first la of diffusion to relate the dispersion coefficient to the turbulent exchange factor as follows:

$$E = \frac{K_{ij}}{0.5\ (L_i + L_{i-1})} \quad sf/day \qquad (8)$$

If the mean concentration in two segments is known then it can be shown from geometry that:

$$\frac{dc}{dx} = \frac{C_{i-1} - C_i}{0.5\,(L_{i-1} + L_i)} \qquad (9)$$

where:

K_i = Dispersion coefficient

A_i = Area in "i" th segment

L_i = Length "i" th segment

L_{i+1} = Length ("i" + 1) th segment

C_i = Concentration in "i" th segment

C_{i+1} = Concentration in ("i" + 1) th segment

N = Mass transferred across the interface substituting equation 9 into Fick's law

$$N_i = \frac{k\,(C_{i-1} + C_i)}{0.5\,(L_{i+1} + L_i)} \quad \text{lbs/sf/day} \qquad (10)$$

multiplying (11) by the cross-sectional area across which turbulent exchange takes place and setting $D = N_i A$ yields:

$$D = \frac{A_i k_i\,(C_i - C_{i-1})}{0.5\,(L_i - L_{i+1})} \qquad (11)$$

which is the expression used in Thomann's model to describe turbulent exchange across a boundary.

The preliminary values of "E" had to be adjusted to bring the calculated and actual values of the dye concentration closer. O'Connor [5] suggested that the calculated "E" should serve only as preliminary values and are not immune to change or adjustment.

The longitudinal dispersion coefficient can be computed from dye mass transfer studies resulting in variations in tidal velocity over a given cross-section and from turbulent diffusion. The variation in tidal velocity is a "shear" type phenomena whereas diffusion is related to concentration and density gradients. In essence, the coefficient does not represent pure dispersion but rather a combination of the dispersion and advection transfer mechanisms of the estuary system.

The magnitude of the longitudinal dispersion coefficient is dependent upon factors such as (1) cross-sectional area, (2) salinity (density) gradients, (3) fresh water inflow, (4) tidal characteristics, and (5) frictional properties.

The dispersion coefficient computed from O'Connor's Model represents a slack tide approximation. Thomann's Model incorporates a coefficient which is time-averaged over a tidal cycle. The two may not be comparable and care must be taken in interchanging the dispersion coefficient between the two models.

APPENDIX B

B. DETERMINATION OF DISPERSION COEFFICIENT

O'Connor has outlined two methods for the determination of "E". One method involves a plot of the following:

$$\text{In } c\sqrt{t}\, e^{kt} \text{ vs. } \frac{(r - ut)^2}{4t} \qquad (13)$$

the slope of which will be 1/E. Although any direct method used for determine "E" will only yield an approximate value, this method introduces more error by the ommission of a term, $\sqrt{E}$.

The other method outlined by O"Connor is a plot of ln c/c_0 squared. The slope of this plot is equal to 1/4Et, from which "E" can be determined and are presented in Tables B-1 through B-12. The "E" thus determined is the dispersion coefficient at the place where the peak occurs.

Table B - 1

POTOMAC ESTUARY DYE ANALYSIS
April 30, 1969

Mile Point	C	C/Co	X^1	$(X^1)^2$
20	0.076	0.160	-10	100
25	0.200	0.560	- 5	25
30	0.355	1.000	0	0
35	0.175	0.492	+ 5	25
37	0.025	0.071	+ 7	49

E = 1/slope * 4t, t = 5.12

E_1 = 1.19

E_t = 2.58

Eave = 1.89

Where:

E = Dispersion coefficient

E_1, E_t = Dispersion coefficient of the leading and trailing edges

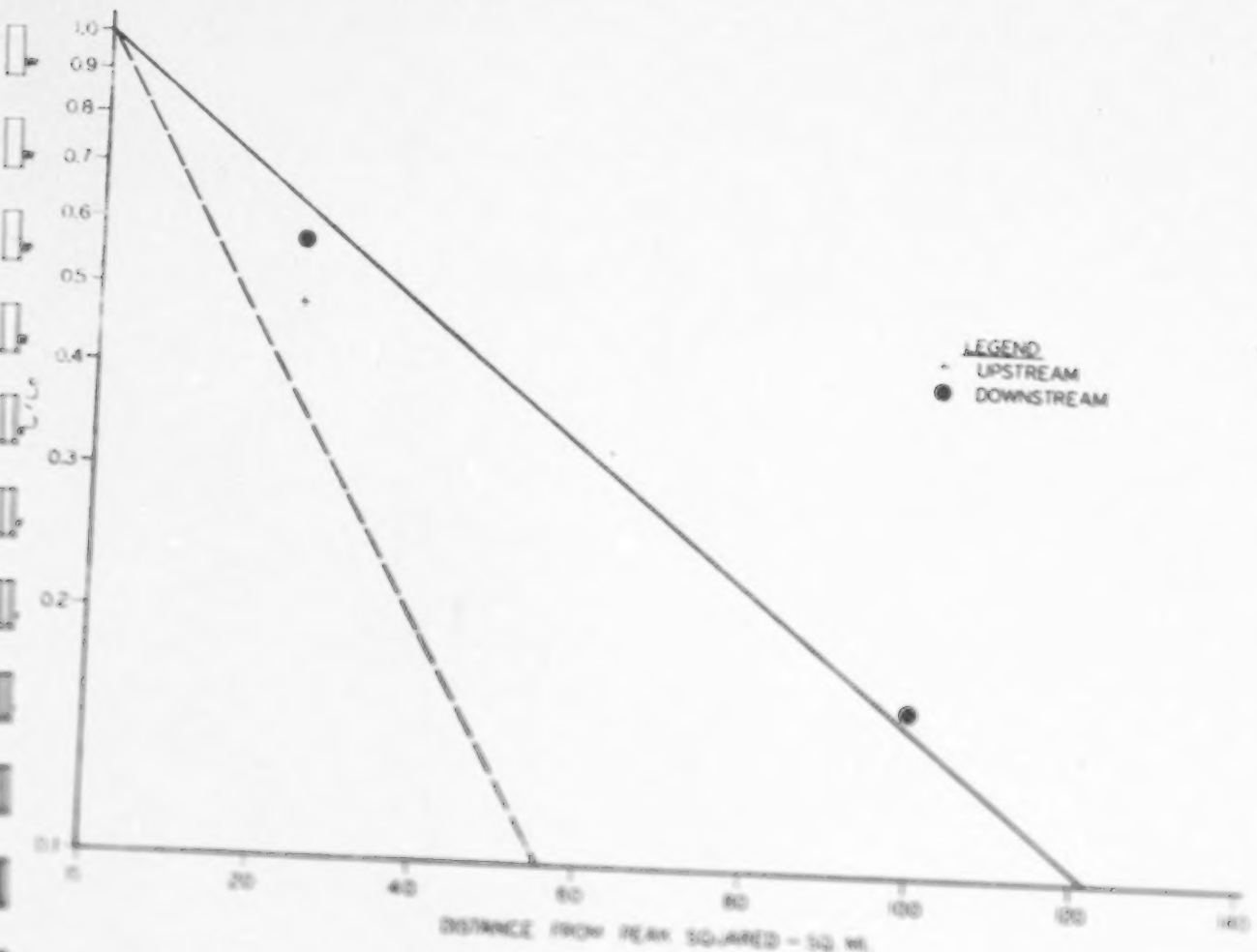
Eave = Average of the leading and trailing edges

t = Time and days

UPPER POTOMAC ESTUARY

APRIL 30, 1969

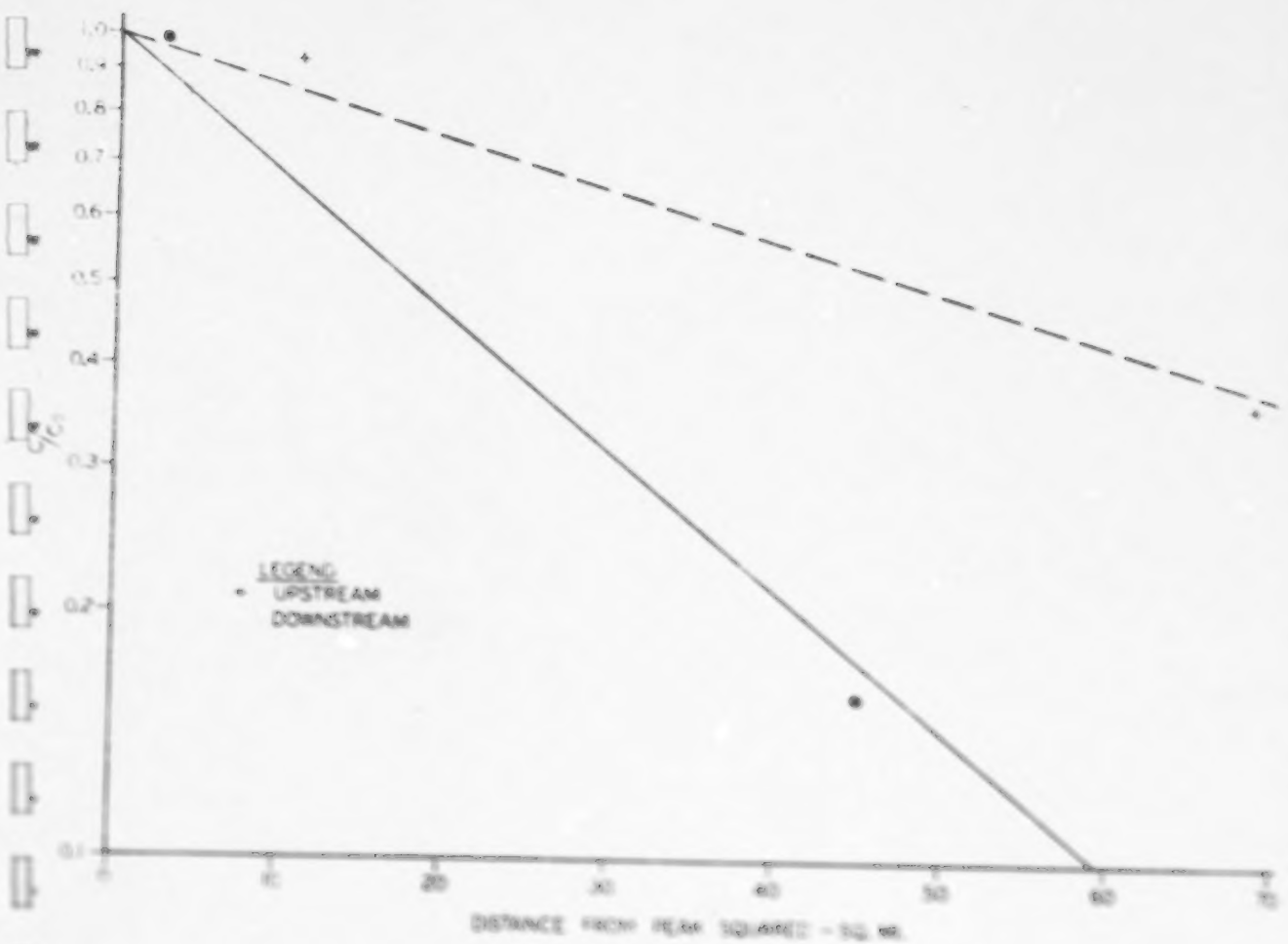
t = 5.12 days



UPPER POTOMAC ESTUARY

MAY 2, 1969

t = 7.16 days



CS1<

FIGURE 8-2

Table B - 2

POTOMAC ESTUARY DYE ANALYSIS
May 2, 1969

Mile Point	C	C/Co	X^1	$(X^1)^2$
20	1.095	0.35	-8.3	68.89
25	1.250	0.93	-3.3	10.89
28.3	1.267	1.00	.0	.00
30	1.262	0.98	+1.7	2.89
35	1.042	0.15	+6.7	44.89

E = 1/slope * 4t, t = 7.16

E_1 = 0.90

E_t = 2.45

Eave = 1.67

UPPER POTOMAC ESTUARY

MAY 5, 1969

t = 10.25 days

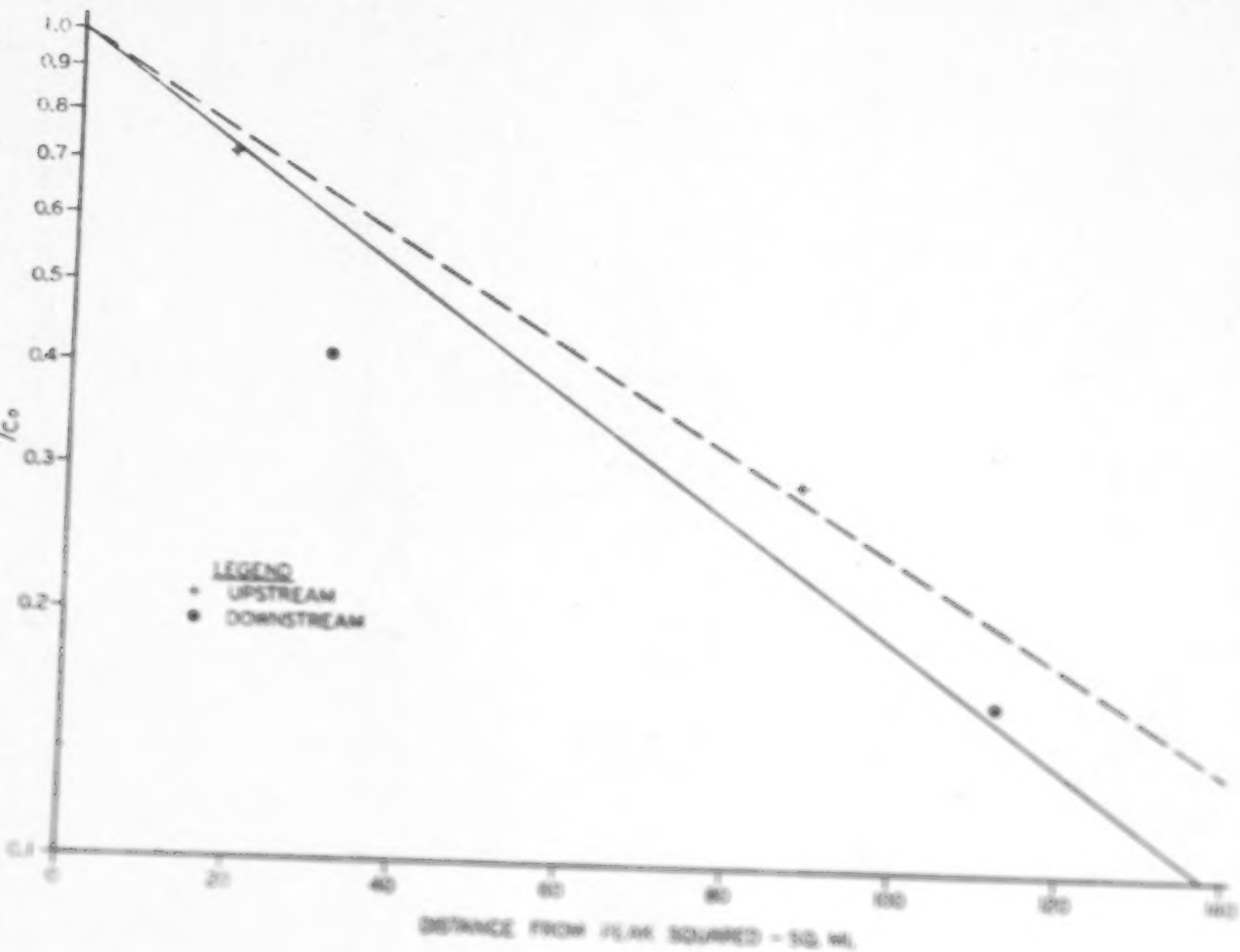


FIGURE B-3

Table B - 3

POTOMAC ESTUARY DYE ANALYSIS
May 5, 1969

Mile Point	C	C/Co	x^1	$(x^1)^2$
20	0.054	0.28	- 9.4	88.36
25	0.138	0.71	- 4.4	19.36
29.4	0.192	1.00	.0	.00
30	0.189	0.94	+ 0.6	.36
35	0.077	0.40	+ 5.6	31.36
40	0.031	0.16	+10.6	112.36

E = 1/slope * 4t, t = 10.25

E_1 = 1.50

E_t = 1.70

Eave = 1.60

UPPER POTOMAC ESTUARY

MAY 5, 1969

t = 10.16 days

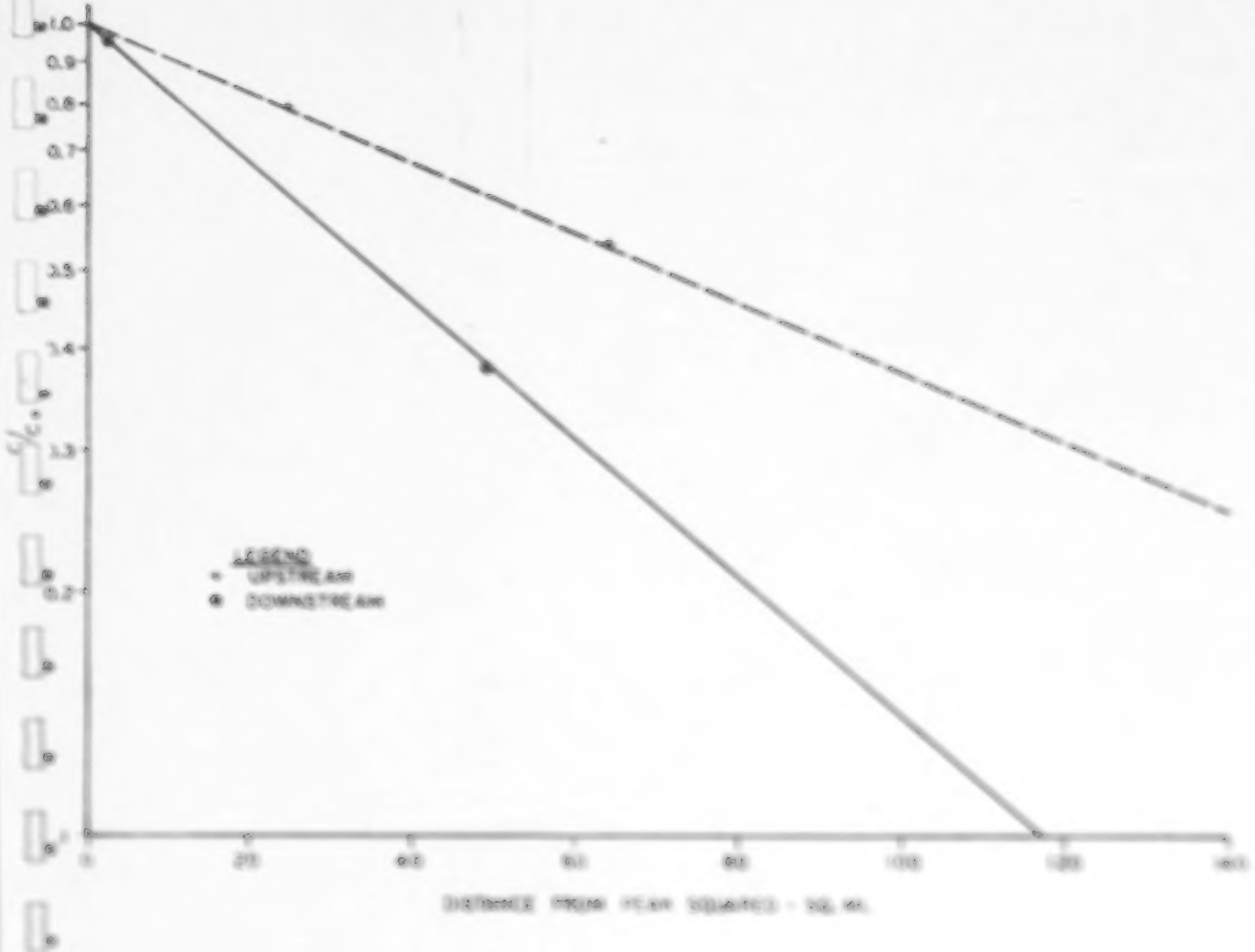


FIGURE 9-1

Table B - 4

POTOMAC RIVER DYE ANALYSIS
May 5, 1969

Mile Point	C	C/Co	X^1	$(X^1)^2$
20	0.115	0.53	- 8	64
23	0.170	0.79	- 5	25
25	0.196	0.92	- 3	9
28	0.213	1.00	0	0
30	0.205	0.96	+ 2	4
35	0.080	0.37	+ 7	49
39	0.020	0.09	+11	121

E = 1/slope * 4t, t = 10.16

E_1 = 1.30

E_t = 2.60

Eave = 1.90

UPPER POTOMAC ESTUARY

MAY 7, 1969

t = 12.08 days

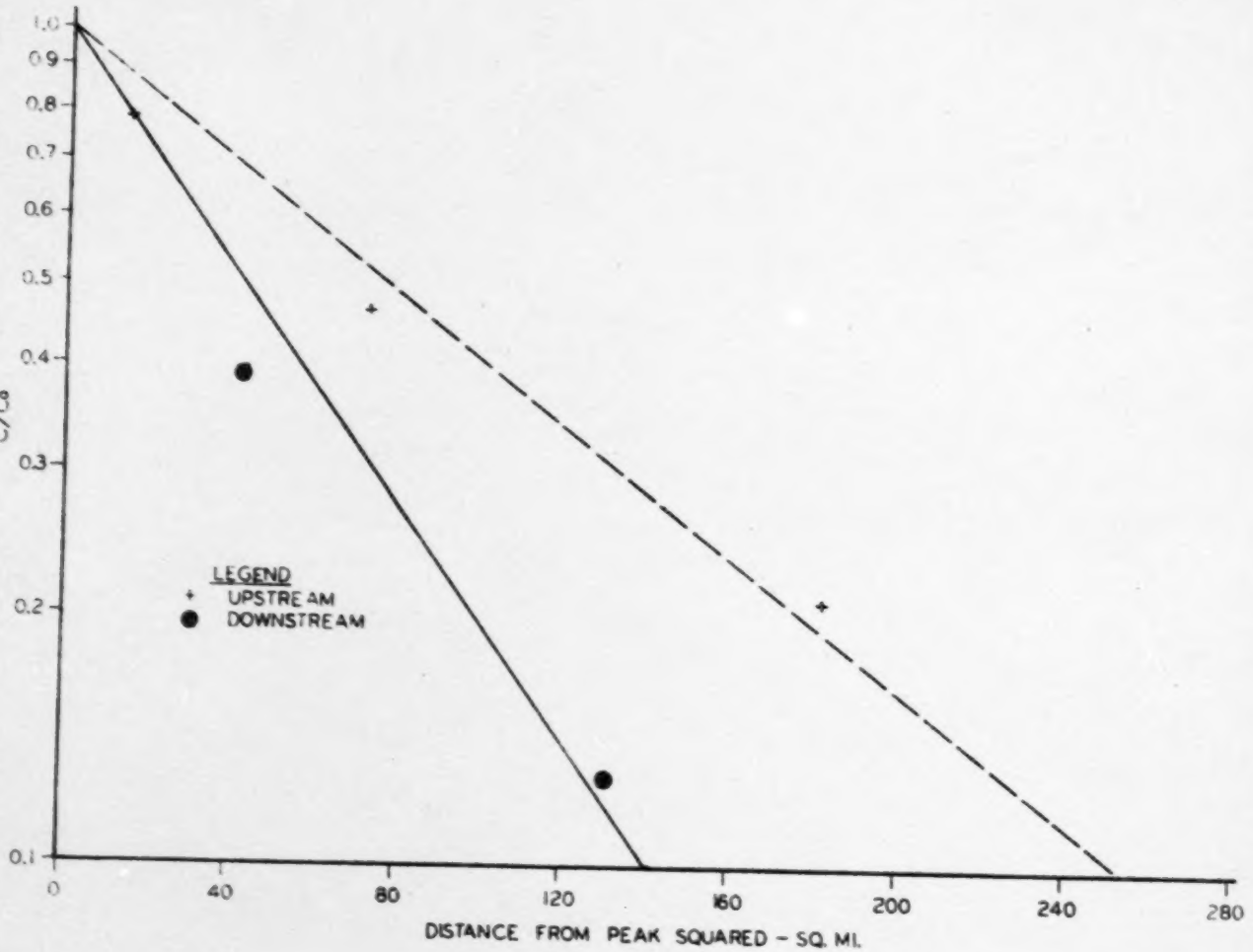


FIGURE 8-5

Table B - 5

POTOMAC ESTUARY DYE ANALYSIS
May 7, 1969

Mile Point	C	C/Co	X^1	$(X^1)^2$
15	.044	0.23655	-13.5	182.25
20	.089	0.47849	- 8.5	72.05
25	.147	0.79032	- 3.5	12.25
28.5	.186	1.00000	.0	.00
30	.172	0.92473	+ 1.5	2.25
35	.072	0.38709	+ 6.5	42.25
40	.024	0.12903	+11.5	132.25

E = 1/slope * 4t, t = 12.08

E_1 = 1.29

E_t = 0.22

Eave = 1.79

UPPER POTOMAC ESTUARY

MAY 10, 1969

t = 15.12 days

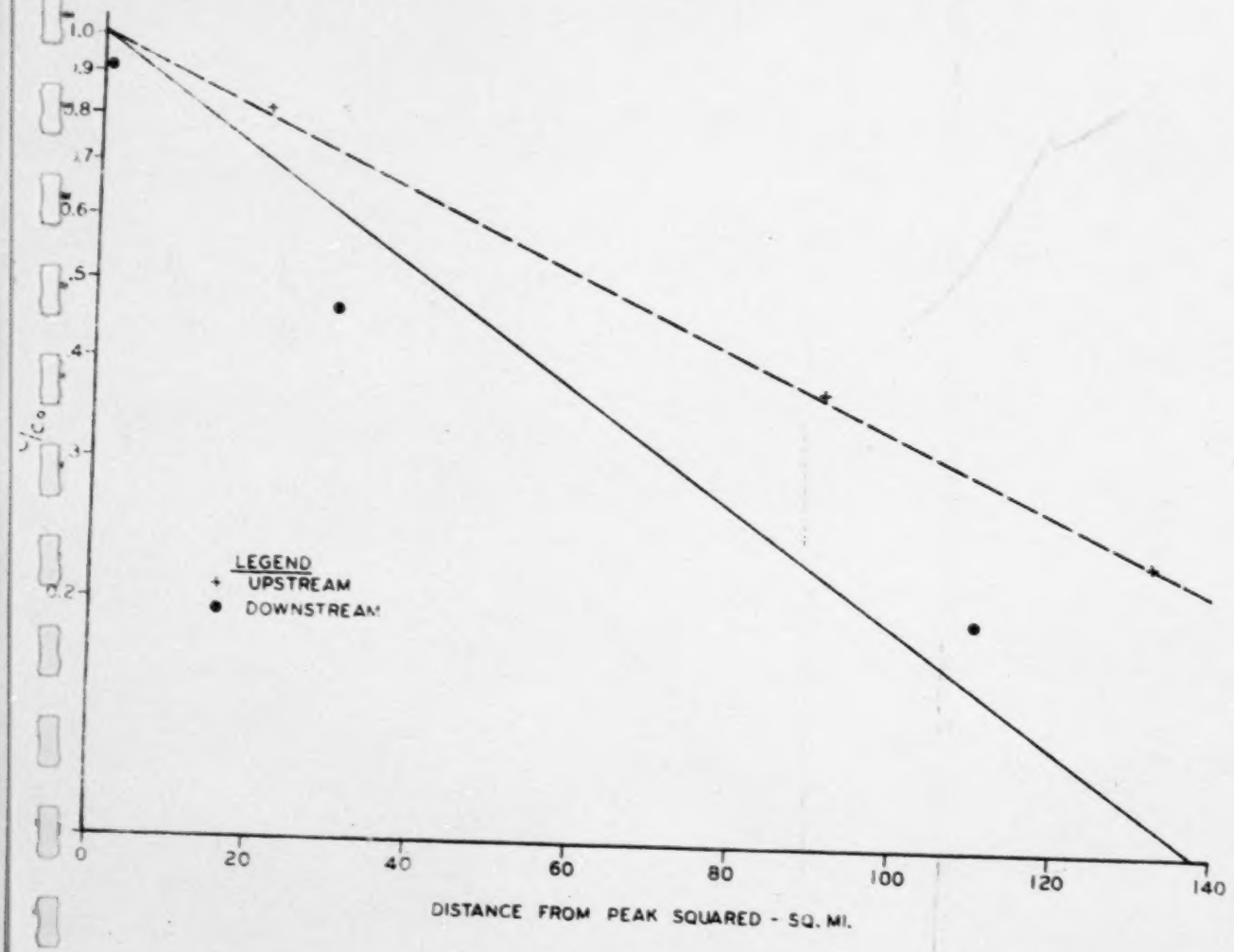


FIGURE B-6

Table B - 6

POTOMAC ESTUARY DYE ANALYSIS
May 10, 1969

Mile Point	C	C/Co	X^1	$(X^1)^2$
23	.062	0.230	-11.5	132.00
25	.062	0.373	- 9.5	90.25
30	.137	0.825	- 4.5	20.25
34.5	.166	1.000	.0	.00
35	.150	0.904	+ .5	.25
40	.076	0.458	+ 5.5	30.25
45	.032	0.193	+10.5	110.00

E = 1/slope * 4t, t = 15.12

E_1 = 1.03

E_t = 1.50

Eave = 1.26

UPPER POTOMAC ESTUARY

MAY 13, 1969

t = 17.25 days

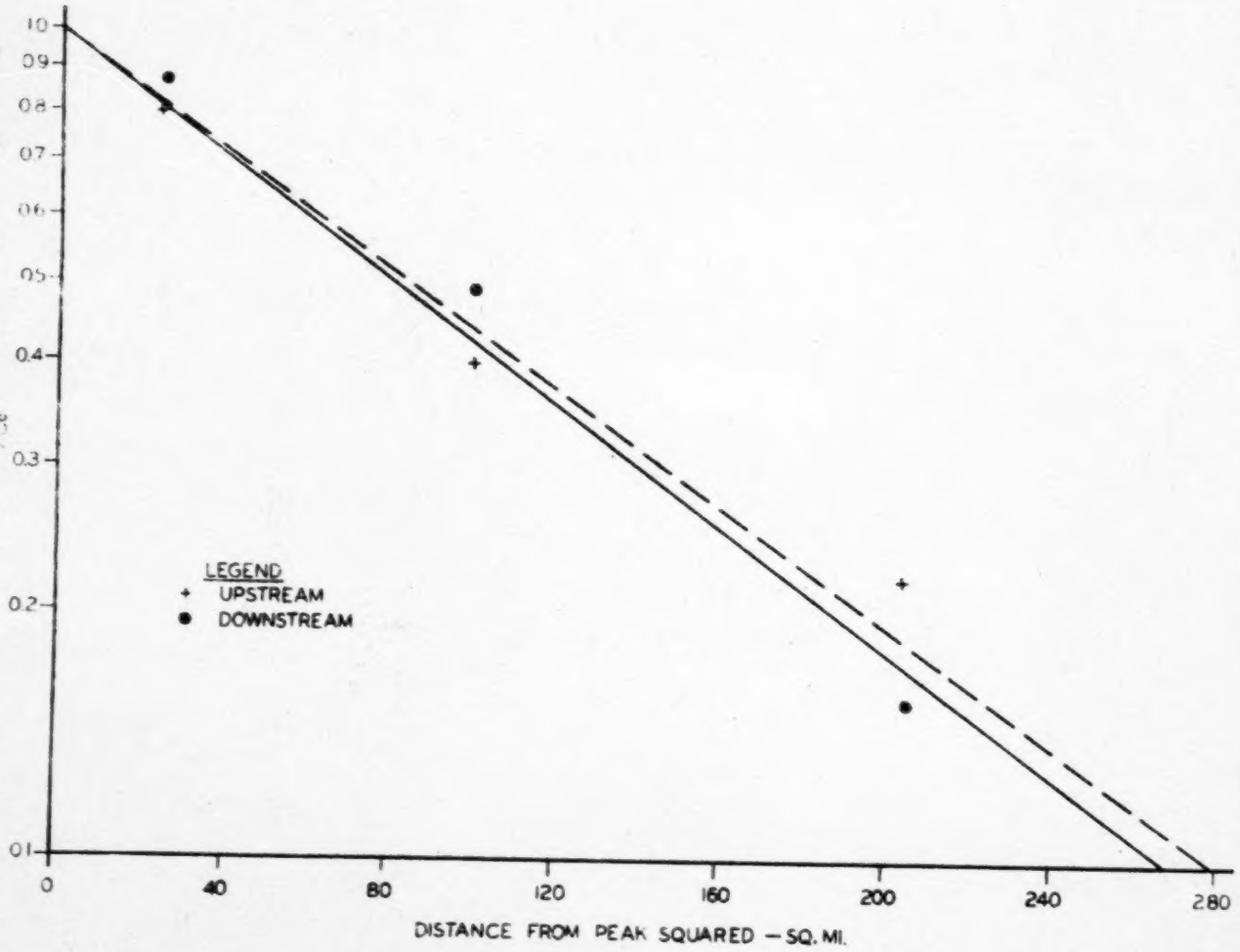


FIGURE B-7

Table B - 7

POTOMAC ESTUARY DYE ANALYSIS
May 13, 1969

Mile Point	C	C/Co	X^1	$(X^1)^2$
15	.028	.224	-15	225
20	.050	.400	-10	100
25	.100	.800	- 5	25
30	.125	1.000	0	0
35	.109	.872	- 5	25
40	.0601	.481	+10	100
45	.0199	.160	+15	225

E = 1/slope * 4t, t = 17.75

E_1 = 1.66

E_t = 1.69

Eave = 1.68

UPPER POTOMAC ESTUARY

MAY 14, 1969

t = 19.13 days

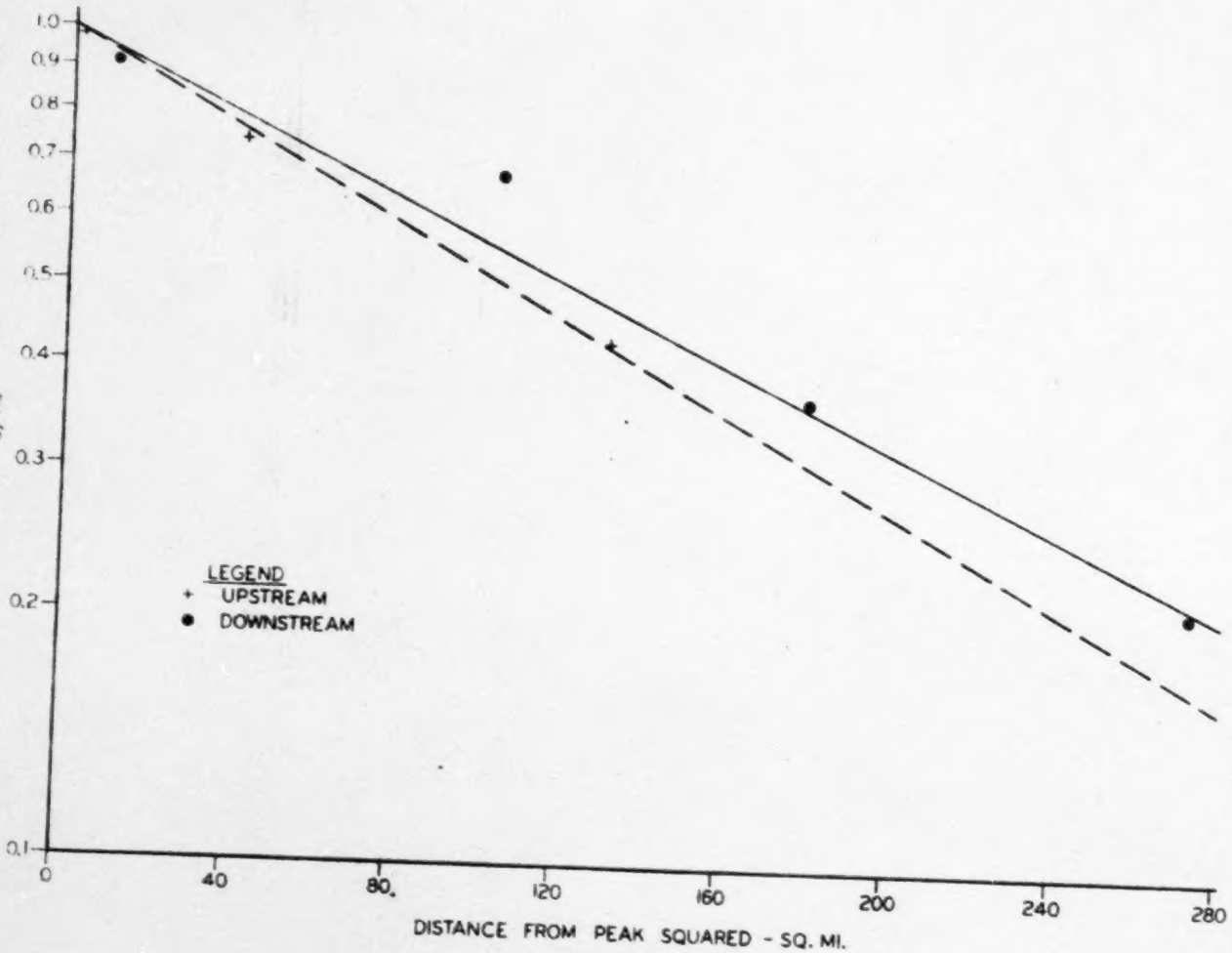


FIGURE B-8

Table B - 8

POTOMAC ESTUARY DYE ANALYSIS
May 14, 1969

Mile Point	C	C/Co	X^1	$(X^1)^2$
17	.022	.20	-16.50	272.25
20	.039	.36	-13.50	182.25
25	.073	.68	- 8.11	65.77
30	.099	.93	- 3.50	12.25
33.5	.106	1.00	.00	.00
35	.105	.99	+ 1.50	2.25
40	.080	.75	+ 6.50	42.25
45	.045	.43	+11.50	132.25

E = 1/slope * 4t, t = 19.13

E_1 = 2.01

E_t = 2.33

Eave = 2.17

UPPER POTOMAC ESTUARY

MAY 20, 1969

t = 25.25 days

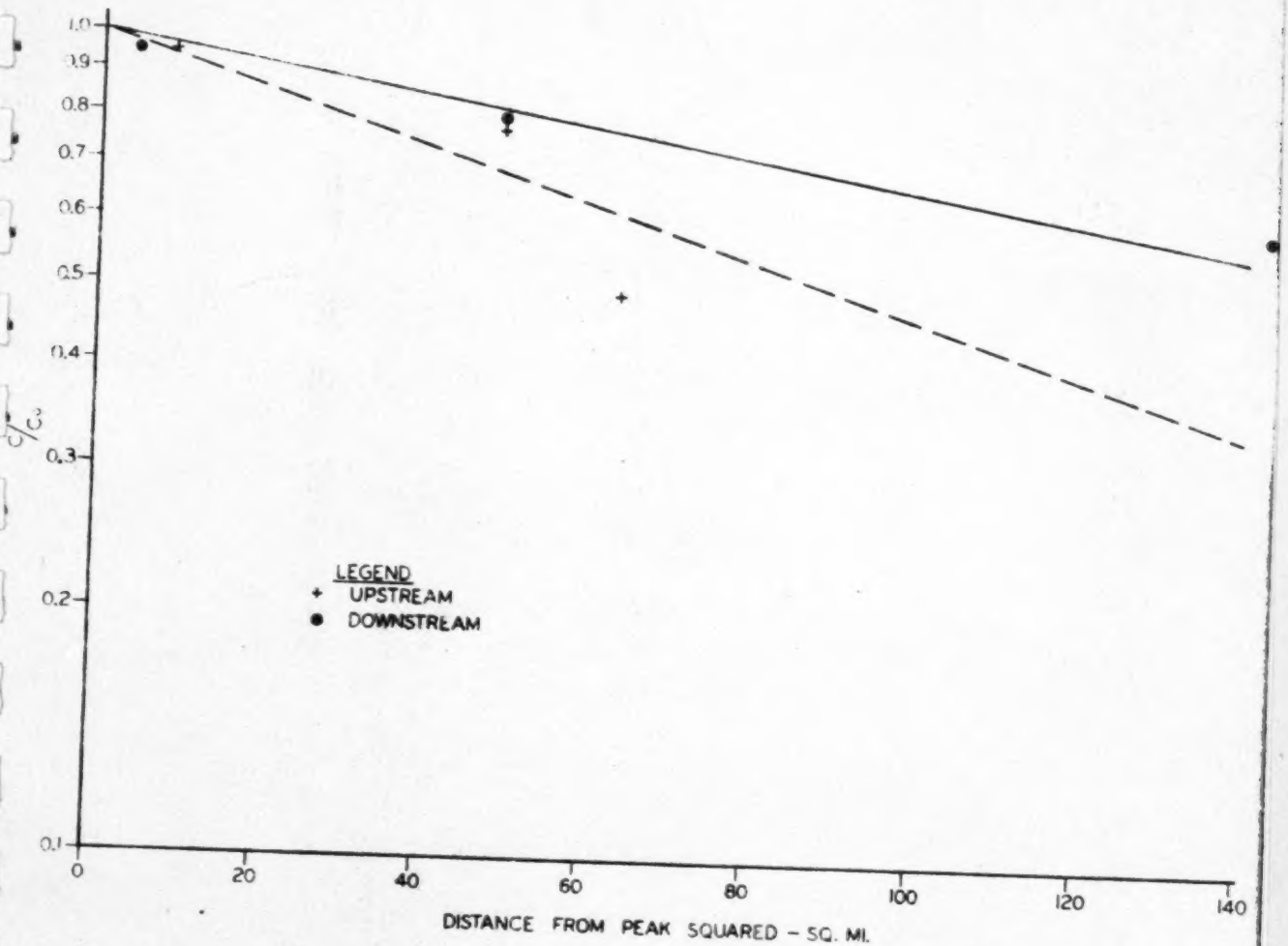


FIGURE B-9

Table B - 9

POTOMAC ESTUARY DYE ANALYSIS
May 20, 1969

Mile Point	C	C/Co	X^1	$(X^1)^2$
20	.046	.419	-13	169
25	.054	.492	- 8	64
30	.105	.958	- 3	9
33	.110	1.000	0	0
35	.106	.960	+ 2	4
40	.087	.790	+ 7	49
45	.075	.680	+12	144

E = 1/slope * 4t, t = 25.25

E_1 = 2.30

E_t = 1.86

Eave = 2.08

UPPER POTOMAC ESTUARY

MAY 26, 1969

t = 31.50 days

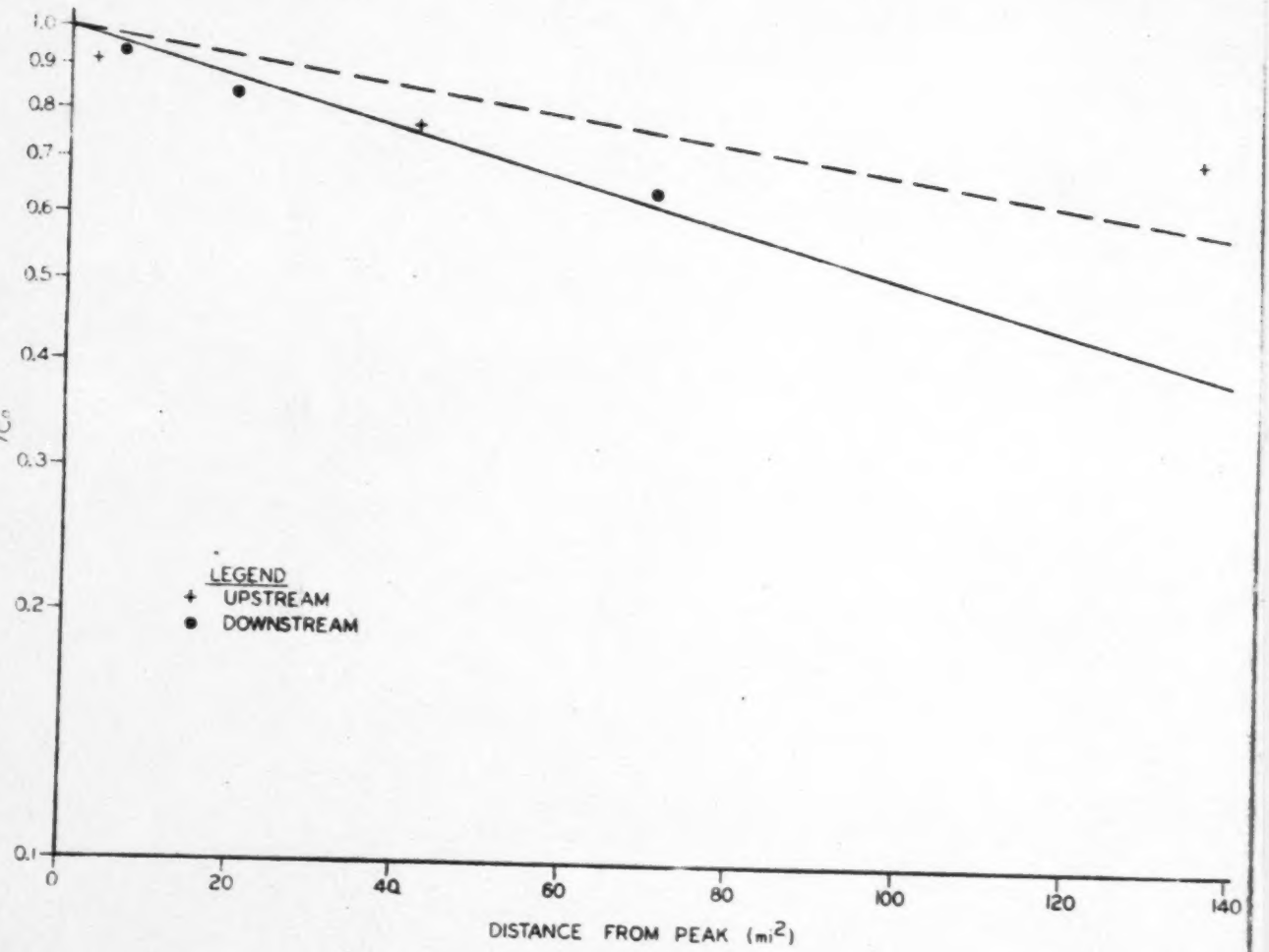


FIGURE B-10

Table B - 10

POTOMAC ESTUARY DYE ANALYSIS
May 26, 1969

Mile Point	C	C/Co	X^1	$(X^1)^2$
25	.057	0.70	-11.50	132.25
30	.063	0.77	- 6.50	42.25
33.5	.075	0.92	- 3.00	9.00
36.5	.081	1.00	.00	.00
39	.077	0.95	+ 2.50	6.25
41	.068	0.83	+ 4.50	20.25
45	.053	0.65	+ 8.50	72.25

E = 1/slope * 4t, t = 31.5

E_1 = 1.19

E_t = 1.84

Eave = 1.57

PISCATAWAY CREEK

JUNE 20, 1969

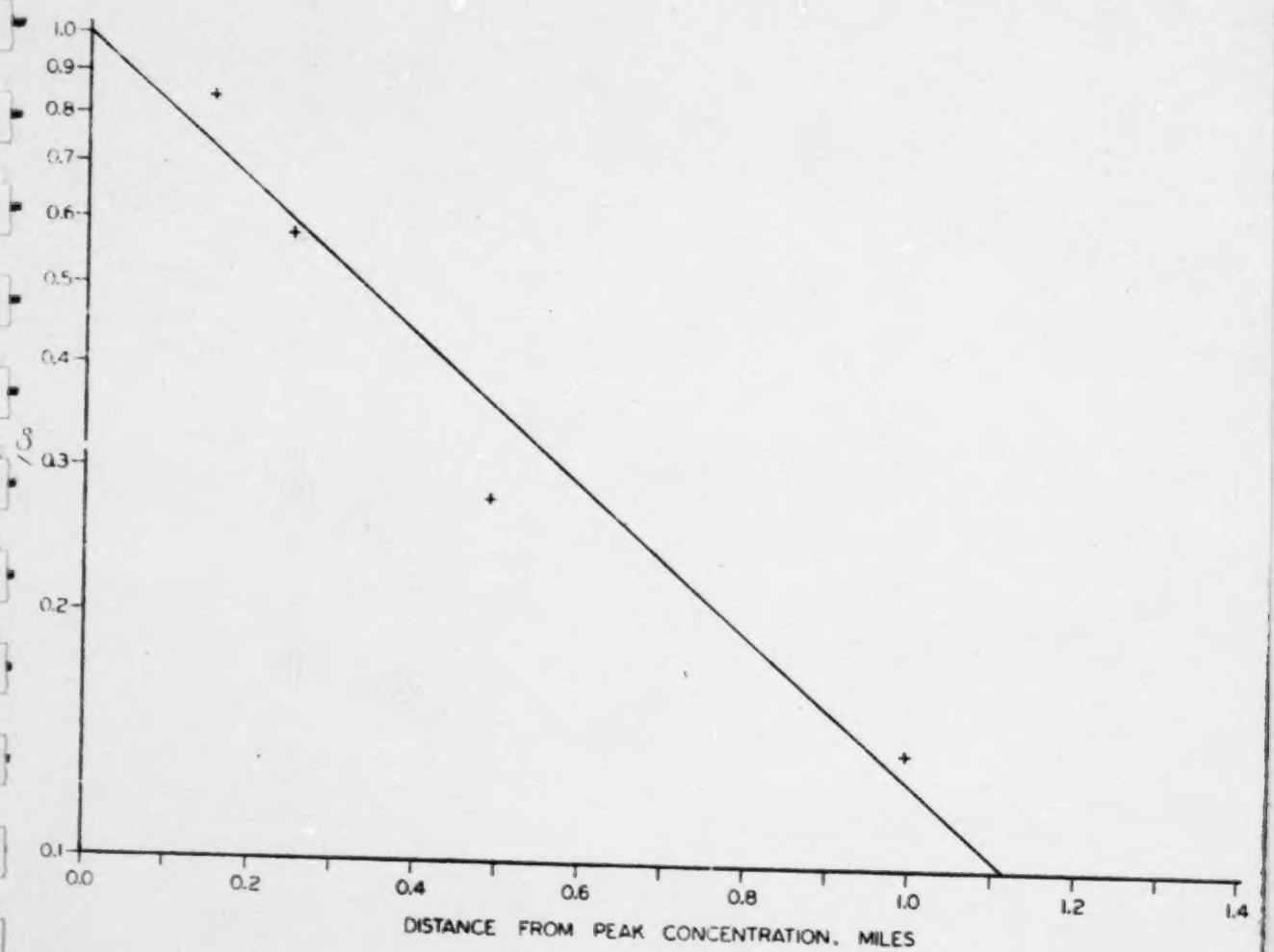


FIGURE B-11

Table B-11

PISCATAWAY CREEK
June 20, 1969
Q = 0

Distance from Peak (X^1) (mile)	$(X^1)^2$	Concentration C (ppb)	C/Co
.00	.000	.70	1.00
.40	.160	.60	.85
.50	.250	.40	.57
.70	.490	.20	.28
1.00	1.000	.10	.14

E = 1/slope * 4t, t = 4.1

E = .03 smpd

PISCATAWAY CREEK
JUNE 23, 1969

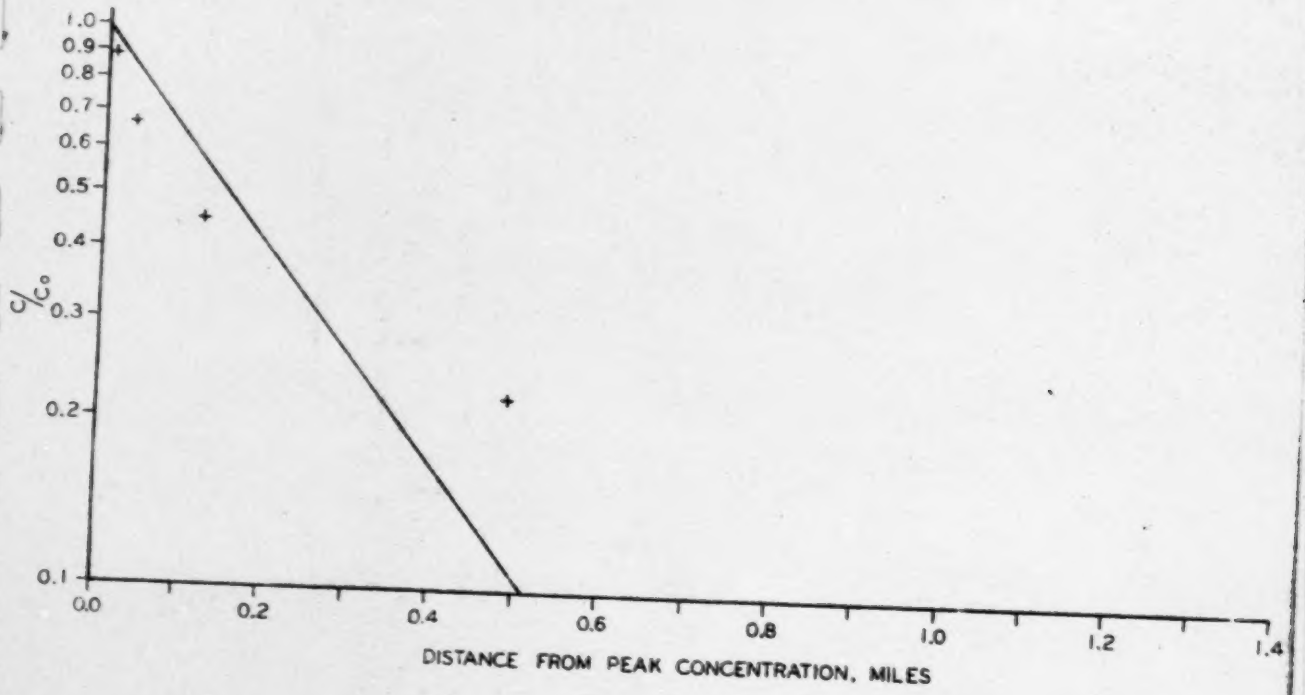


FIGURE B-12

Table B-12

PISCATAWAY CREEK
June 23, 1969
Q = 0

Distance from Peak (X^1) (mile)	$(X^1)^2$	Concentration C (ppb)	C/Co
.00	.0000	.45	1.00
.05	.0025	.40	0.89
.20	.0400	.30	0.67
.35	.1225	.20	0.45
.70	.4900	.10	0.22

E = 1/slope * 4t, t = 7.2

E = .08 smpd

TABLE C-1

PISCATAWAY CREEK

1968

Chesapeake Technical Support Laboratory

Date Sample Taken	Time Sample Taken	Water Temp. °C	Total P PO_4 mg/l	TKN mg/l N	NH_3 mg/l N	NO_2 NO_3 mg/l NO_3-N	Chloro-phyll a ug/l	BOD mg/l	DO mg/l	Fecal Coliform MPN/100ml	Coliform MPN/100ml
STATION P 0-INDIAN HEAD HIGHWAY - ROUTE 210											
7-11	1225	21.5	.972			1.540	3.00	4.56	7.65		
8-14	0930	22.2		.544		1.130	2.25	3.04	7.54		
8-15	1225	22	1.078	.911		1.36	4.50	2.02	8.12		
8-16	1215	23	1.108	.482		1.318	4.50	3.94	7.62		
9-16	1300	19	1.136	.778		1.251	1.50	3.26*	8.72		
STATION P 1-PUMPING STATION - ABOVE DISCHARGE											
7-11	0930	23	2.510			.317	84.00	14.32	3.18	230	43.000
8-14	1000	23	.845	2.589		.188	43.50	6.84	2.31		
8-16	1140	23	3.437	4.723		.194	5.25	12.80	4.02		
9-16	1020	19	3.408	2.801		.521	15.00	8.54*	2.58		
STATION P 2-FIRST BEND - ABOVE DISCHARGE											
7-11	0955	24.5	2.261			.372	173.20	15.10	5.66	230	7.500
8-14	1005	23	1.193	LA		.170	72.75	8.36	1.96		
8-15	1052	23	2.466	3.321		.232	57.50	9.80	3.25		
8-16	1135	24.5	4.017	5.759		.273	133.50	13.74	3.78		
9-16	1030	19	3.808	3.044		.656	24.75	8.14*	2.56		
STATION P 3-NEAR WHITE BARRELS NEXT TO FIRST HOME											
7-11	1000	25	1.886			.350	220.50	14.52	8.09	93	23.000
8-14	1020	23.5	1.198	3.203		.217	132.00	3.44	6.52		
8-15	1045	24.2	3.628	5.645		.343	7.50	11.04	6.57		
8-16	1125	24.5	2.553	3.277		.317	123.00	8.74	6.52		
9-16	1040	22	3.875	3.196		.572	50.25	8.88*			
STATION P-3A-ON TRIB. OPPOSITE PLANT NEAR POSTS IN CHANNEL											
8-14	1040	21.5	.879	.937							
8-15						.642	43.50	6.98	6.59		
8-16	1055	23.5	1.169	1.867		.628	82.50	7.36	7.01		
9-16	1040	21	1.390	.614		1.087	2.25	2.58*	7.37		

LA - Laboratory accident
*6-day BOD

TABLE C-1 (Continued)

Date Sample Taken	Time Sample Taken	Water Temp. °C	Total P PO_4 mg/l	TKN mg/l N	NH_3 mg/l N	NO_2+NO_3 mg/l NO_3-N	Chloro-phyll a ug/l	BOD mg/l	DO mg/l	Fecal Coliform MPN/100ml	Coliform MPN/100ml
STATION P - 3B-ON TRIB. OPPOSITE PLANT NEAR CHANNEL TO ROAD											
8-14	1048	23.5	.990	2.291		.177	130.50	9.78	6.78		
8-15	----------					NO SAMPLE					
8-16	1105	22.5	1.424	.717		1.195	18.00	3.96	6.04		
9-16	1120	21	1.203	.462		1.076	.75	2.18*	7.24		
STATION P -3C-NEAR END OF CATTAILS IN OPPOSITE TRIB.											
8-14	1055	24	1.023	2.633		.031	207.75	9.32	10.92		
----------						NO SAMPLE					
8-16	1110	23	.864	.518		1.273	195.75	3.74	6.87		
9-16	1110	19.5	1.350	1.057		.969	10.50	2.94*	6.73		
STATION P -3D-IN MARSH - 1st TRIB. TO RIGHT											
9-16	1045	23	2.873	2.633		.617	43.50	10.36	6.73		
STATION P -4-FARMINGTON LODGE POINT IN BAY											
7-11	1010	26	1.168			.419	201.0	12.62	12.05	15	230
8-14	1110	25.5	1.004	2.475		.244	209.25	7.56	12.38		
8-15	1110	25	2.006	3.003		.163	154.5	14.90	12.90		
8-16	1040	25	1.475	3.102		.180	219.75	9.64	9.57		
9-16	1140	25.5	1.563	1.994		.614	147.00	13.28*	12.40		
STATION P -5-IN BAY -OUT FROM MARINA											
7-11	1020	26.5	1.214			.667	72.0	11.90	4.50	210	750
8-14	1120	25.5	.918	1.899		970	146.25	8.54	7.93		
8-15	1115	25.5	1.350	2.563		.169	173.25	11 82	10.88		
8-16	1030	25.5	1.037	2.813		.108	171.00	11 20	12.88		
9-16	1150	26	1.470	2.158		.474	127.50	15.10*	14 31		
STATION P -6-OFF POINT BELOW MARINA IN CHANNEL											
7-11	1030	26.5	.968			.744	43.5	11.54	5.05	230	430
8-14	1115	26	.967	1.987		1.022	162.75	8.00	6.20		
8-15	1120	26	1.416	2.440		1.11	137.25	12.50	6.53		
8-16	1020	26	1.007	LA		.473	173.25	10.72	8.69		
9-16	1205	25.5	2.392	4.665		.538	34.50	17.18*	14.11		
STATION P -7-MID BAY - OFF FIRST TWO CHANNEL MARKERS											
7-11	1035	26.5	.943			.971	78.0	11.74	4.82	43	230
8-14	1120	26	.971	1.785		1.190	111.75	9.06	5.68		
8-15	1124	26	1.688	2.165		1.36	9.00	11.34	5.39		
8-16	1010	26	5.858	8.235		.807	180.00	16.52	6.06		
9-16	1215	26	3.207	6.342		1.069	345.00	15.52*	.08		

TABLE C-1 (Continued)

Date Sample Taken	Time Sample Taken	Water Temp. °C	Total P PO_4 mg/l	TKN mg/l N	NH_3 mg/l N	NO_2+NO_3 mg/l NO_3-N	Chloro-phyll a_o ug/l	BOD mg/l	DO mg/l	Fecal Coliform MPN/100ml	Coliform MPN/100ml	Turbi-dity JTU
STATION P - 8-CONFLUENCE WITH POTOMAC RIVER - MID CHANNEL AT MARKERS												
7-11	1040	26.5	.838			1.160	76.50	10.58	4.21	75	390	
8-14	1130	26		2.348		1.600	184.50	8.90	6.88			
8-15	1126	26.5		2.093		1.25	135.75	14.58	8.24			
8-16	1000	26	1.078	1.771		1.136	138.00	10.42	5.35			
9-16	1210	26.5	2.606	4.405		1.116	262.50	13.80*	5.35			
STATION P - 9-OFF MONITOR STATION BUOY - POTOMAC RIVER												
7-11	1045	27	.883			.992	78.75	10.60	4.18	93	230	
8-14	1130	26	1.130	1.728		1.240	199.50	9.28	5.38			
8-15	1135	26.5	1.200	2.024		1.39	113.25	9.24	4.86			
8-16	0935	26	.976	1.633		1.363	303.00	8.62	3.08			
9-16	1220	24.5	1.737	LA		1.113	135.00	11.10*	5.64			
STATION P -10-BUOY 76 IN POTOMAC RIVER												
7-11	----	26.5	.822			1.232	76.50	10.30	4.21	43	430	
8-14	1150	26	1.179	2.405		3.210	192.00	11.60	5.27			
8-15	1145	26	1.191	2.171		1.41	116.25	9.04	5.66			
8-16	0950	26	1.525	4.434		1.246	130.50	12.32	3.68			
9-16	1230	--	8.486	6.576		.772	7320.00	>14.14*	5.74			
PISCATAWAY STP												
8-14	--INFLUENT	--	8.618	9.639	7.713	1.221	6.75	77.90				
8-14	--EFFLUENT	--	11.034	11.165	12.669	.510		17.50				
9/15-16	--INFLUENT	--	37.416	25.570	14.21		27.00	>153.20				
9/15-16	--EFFLUENT	--	26.057	16.171	13.92		.75	24.00				
PISCATAWAY CREEK - FT. WASHINGTON - STATION 7												
5-15	1500	19.5	1.505	2.27	1.669	.344	18.00	3.8	1.39 T.			13
6-10	1422	26.6	.589						1.65 B.			
6-24	1400	27.1	1.120		.625	.547	81.75	3.8*				18
7-8	--	28.7	1.022	1.800	1.401	LA	4.50					14
7-22	1422	30.4	.788	2.503	1.246	.470	28.50	LA*				18
8-5	--	29.5	1.465	1.762	.235	1.620		7.4*				11
				1.290	.066	1.756	148.50	12.1*				

LA - Laboratory accident

* Analysis done by Blue Plains Personnel.

TABLE C-2

PISCATAWAY CREEK SURVEY

April 30 - May 1, 1969

Chesapeake Technical Support Laboratory

Station	Sta. No.	Sample Time	Water Temp. °C	Total P mg/l PO_4	TKN mg/l N	NO_2 NO_3 NO_3-N mg/l	NH_3 N mg/l	Chloro-phyll a_o ug/l	Chloro-phyll a_a ug/l	Turbi-dity JTU	DO mg/l	BOD mg/l	TOC* mg/l
Farmington Lodge Pt. in Bay	P-4	1120	17.5	2.640	1.958	.705	.593	136.50		22	7.88	12.36	8.8
In Bay - Out from Marina	P-5	1105	18.5	1.320	.959	.528	.090	157.50		18	9.82	11.48	10.0
Off Point- Below Marina in Channel	P-6	1100	18.5	1.210	1.132	.447	.440	152.25		16	9.70	10.82	9.4
Mid-Bay, Off First Two Channel markers	P-7	1055	18.5	1.254	1.219	.460	.250	114.75		13	8.53	9.48	6.4
Confluence with Potomac Mid channel at markers	P-8	1045	18.5	1.374	1.092	.434	.395	80.25		17	7.64	8.80	6.6
Pumping Sta. - Above Discharge	P-1	1100	14	2.781	3.570	1.186	2.400	24.00		5.5	7.46	4.40	9.6
First Bend - Above Discharge	P-2	1045	14.5	4.292	5.514	.846	1.303	48.75		8.5	7.15	5.53	10.0
Near White Barrels Next to first home	P-3	1030	15	3.354	2.571	.748	.920	109.50		14	10.19	8.52	9.8
On trib. Opposite Plant near posts channel	P-3A	1200	12	.906	.440	.950	.033	6.00		6.5	9.12	1.58	4.0
On trib. Opposite Plant near channel to road	P-3B	1140	12	.771	.320	.981	.018	9.00		7	9.02	1.69	4.8
Near end of Cattails in Opposite trib.	P-3C	1125	13	.854	.653	.981	.023	13.50		12	8.20	2.20	5.4
Off Monitor Sta. Buoy Potomac River	P-9	1230	18.5	1.323	1.958	.580	.763	46.50		5.5	6.84	5.50	4.2
Buoy 76 in Potomac River	P-10	1245	18.5	1.427	1.758	.654	.868	48.00		8	7.10	10.40	9.2

*Analysis run by FWPCA-DC Joint Pilot Plant.

TABLE C-3

PISCATAWAY CREEK SURVEY

May 13. 1969

Chesapeake Technical Support Laboratory

Station	Sta. No.	Sample Time	Water Temp. °C	Total P mg/l PO_4	TKN mg/l N	NO_2 NO_3 NO_3-N mg/l	NH_3 N mg/l	Chloro-phyll a_c ug/l	Chloro-phyll a_a ug/l	Turbi-dity JTU	BOD mg/l	DO mg/l	TOC* mg/l
Pumping Sta. - Above Discharge	P-1	1005	15	5.880	8.392	.573		18.75				4.34	19.0
First Bend - Above Discharge	P-2	1040	15	5.286	7.460	.660		16.50				4.53	21.3
Near White Barrels Next to first Home	P-3	1120	17	28.896	21.446	.450		6.75				6.36	26.0
Farmington Lodge Pt. in Bay	P-4	1150	18.5	2.240	5.808	.643		121.50				11.52	17.0
In Bay- Out from Marina	P-5	1210	18.5	1.680	3.996	.338		81.75				12.50	14.8
Off Point- Below Marina in Channel	P-6	1210	18.5	1.736	3.590	.286		90.75				11.49	14.2
Mid-Bay, Off First Two Channel markers	P-7	1220	19	1.848	3.796	.197		39.00				6.96	16.2
Confluence with Potomac Mid Channel at markers	P-8	1225	19.5	1.870	3.543	.235		48.75				6.61	14.9
Off Monitor Sta. Buoy Potomac River	P-9	1230	20	2.464	3.330	.129		31.50				3.15	15.1
Buoy 76 in Potomac River	P-10	1245	20	2.262	3.463	.173		20.25				3.41	15.2

TABLE C-4

PISCATAWAY CREEK SURVEY

June 23, 1969

Chesapeake Technical Support Laboratory

Station	Sta. No	Sample Time	Water Temp. °C	Total P mg/l PO_4	TKN mg/l N	NO_2 NO_3 N mg/l	NH_3 N mg/l	Chlorophyll a_o ug/l	Chlorophyll a_a ug/l	Turbidity JTU	BOD mg/l	DO mg/l	TOC* mg/l
Indian Head Hwy. Bridge Rt. 210	P-0	1335	27	1.773	.466	1.532	.16	7 50	2.25	30.0		5.92	8.0
Pumping Sta. - Above Discharge	P-1	1149	24	3.5978	1.524	.882	.41	75.0	60.00	25		3.78	12.94
First Bend - Above Discharge	P-2	1142	24	3.8778	2.33	1.074	.58	100.5	81.00	30		5.88	10.91
Near White Barrels Next to first home	P-3	1138	25	2.3159	1.906	.832	.51	126.0	99.75	25		8.04	11 08
On trib Opposite Plant near posts channel	P-3A	1220	25	1.9928	1.720	.732	.25	114.75	88.50	25		9.04	11.14
On trib. Opposite Plant near channel to road	P-3B	1218	25	1.5080	1.848	.719	.26	132.75	101.25	30		7.54	11.55
Near end of Cattails in Opposite trib.	P-3C	1212	25	1.6911	1.860	.714	.16	155.25	109.50	20		6.78	9.56
Farmington Lodge Pt. in Bay	P-4	1130	26	1.7540	1.418	.924	.15	126.0	98.25	20		8.52	11.86
In Bay - Out from Marina	P-5	1122	25.5	2.0143	1.430	1.111	.18	114.0	87.75	20		7.88	11 14
Off Point- Below Marina in Channel	P-6	1118	25.5	2.1005	1.174	1.594	.17	108.0	90.00	15		6.61	9.72
Mid-Bay, Off First Two Channel markers	P-7	1117	25.5	2.2728	1.268	1.650	.25	86.25	68.25	15		5.00	7.97
Confluence with Potomac Mid channel at markers	P-8	1115	26	2.1005	1.442	1.675	.30	78.75	66.00	15		4.68	8.85
Off Monitor Sta. Buoy Potomac River	P-9	1105	26	2.7082	1.232	1.670	.26	104.25	93.00	10		4.50	7.44
Buoy 76 in Potomac River	P-10	1055	25	2.0143	1.36	1.707	.25	106.50	87.00	15		4.31	9.53

*Analysis run by FWPCA-DC Joint Pilot Plant.

TABLE C-5

PISCATAWAY CREEK SURVEY

July 15, 1969

Chesapeake Technical Support Laboratory

Station	Sta. No.	Sample Time	Water Temp. °C	Total P mg/l PO_4	TKN mg/l N	NO_2 NO_3 NO_3-N mg/l	NH_3 N mg/l	Chloro-phyll a_o ug/l	Chloro-phyll a_a ug/l	DO mg/l	BOD mg/l	Coliform MPN 100ml	Fecal Coliform MPN 100ml
Indian Head Hwy. Bridge Rt. 210	P-0	1040	25	1.8134	.816	1.08	.225	58.5	43.50	4.75	5.90		
Pumping Sta. - Above Discharge	P-1	0800	24.6	6.2072	3.408	2.5	1.50	125.25	105.75	4.25	12.34	15,000	230
First Bend- Above Discharge	P-2	0815	24.6	3.7098	2.615	1.54	.535	200.25	153.75	5.57	14.92	9,300	1,500
Near White Barrels Next to first home	P-3	0820	27	2.0518	2.328	.170	.028	246.75	216.75	11.05	14.56	4,300	430
On trib. Opposite Plant near posts chan-nel	P-3A	0830	26	1.8756	2.046	.465	.031	191.25	141.75	7.34	11.12	39,000	230
On trib. Opposite Plant near channel to road	P-3B	0835	26	1.3160	1.822	.420	.030	199.5	144.75	5.93	11.24	23,000	430
Near end of Cattails in Opposite trib.	P-3C	0840	26	1.2953	3.138	.025	.032	203.25	164.25	8.31	11.34	4,300	43
Farmington Lodge Pt. in Bay	P-4	0850	27.5	1.5129	2.316	.020	.024	206.25	240.75	15.42	16.64	210	3.6
In Bay - Out from Marina	P-5	0900	27	1.6269	1.201	1.97	.030	208.25	105.00	7.56	10.84	9.3	15
Off Point- Below Mar-ina in Channel	P-6	0905	27.5	1.3989	1.144	1.96	.050	148.5	109.50	5.70	8.80	750	21
Mid-Bay, Off First Two Channel markers	P-7	0910	28	1.4508	1.241	1.97	.045	138.0	102.75	6.50	8.70	93	9.1
Confluence with Poto-mac Mid channel at markers	P-8	0920	28	1.4300	1.149	1.97	.051	103.5	80.25	5.87	8.62	43	9.1
Off Monitor Sta. Buoy Potomac River	P-9	0940	27	1.2331	1.661	1.26	.164	126.75	108.75	5.38	MSQ	93	3.6
Buoy 76 in Potomac River	P-10	0925	28	1.6269	1.115	1.67	.029	136.5	116.25	6.45	9.00	43	3.6

TABLE C-6

PISCATAWAY CREEK SURVEY

August 5, 1969

Chesapeake Technical Support Laboratory

Station	Sta. No.	Sample Time	Water Temp. °C	Total P mg/l PO_4	TKN mg/l N	NO_2 NO_3 NO_3-N mg/l	NH_3 N mg/l	Chloro-phyll a_o ug/l	Chloro-phyll a_a ug/l	DO mg/l	BOD mg/l	Coliform MPN 100ml	Fecal Coliform MPN 100 ml
Indian Head Hwy. Bridge Rt. 210	P-0	1615	22	.482	.261	.490	.097	3.75	15.00	7.12	4.60	93,000	7,500
Pumping Sta. - Above Discharge	P-1	1430	22	1.032	.671	.253	.146	12.00	86.25	3.78	4.28	150,000	9,300
First Bend - Above Discharge	P-2	1420	22	2.391	1.329	.870	.510	18 00	14.25	4.94	5.04	43,000	4,300
Near White Barrels Next to first home	P-3	1440	22	1.109	.787	.526	.242	9.75	93.00	5.61	3.98	4,300	2,300
On trib. Opposite Plant near posts channel	P-3A	1507	21	.532	.606	.509	.119	3.00	3.00	6.92	4.20	23,000	4,300
On trib. Opposite Plant near channel to road	P-3B	1500	21	.503	.581	.496	.118	6.00	3 00	7.01	3.42		
Near end of Cattails in Opposite trib.	P-3C	1522	21	.541	.568	.495	.119	3.00	6.75	6.88	3.13	23,000	23,000
In Marsh - 1st trib. to right	P-3D	1400	22.5	1.522	1.200	.770	.568	30 00	109.50	4.45	8.22	93,000	23,000
Farmington Lodge Pt. in Bay	P-4	1350	24	.850	1.277	.527	.248	120 75	95.25	8.13	7 60		
In Bay - Out from Marina	P-5	1345	26	.854	1.458	.616	.710	6.00	117.75	4.04	6 54	9,300	4,300
Off Point- Below Marina in Channel	P-6	1325	26	.861	1.497	.642	.760	66.00	120.00	3.54	5.86	4,300	930
Mid-Bay. Off First Two Channel markers	P-7	1317	26.5	.795	1.561	.630	.740	77.25	55.50	3 00	5.92	240,000	930
Confluence with Potomac Mid channel at markers	P-8	1313	26.5	.974	1.445	.597	.799	57.00	78.75	2.31	6 22	75,000	2,300
Off Monitor Sta. Buoy Potomac River	P-9	1305	26.5	.943	1.509	.607	.780	65.25	54.75	2.43	7.22		
Buoy 76 in Potomac River	P-10	1256	27	.948	1.355	.580	.770	54.75	9.00	2.63	6.28	43,000	930

TABLE C-7

PISCATAWAY CREEK SURVEY

December 8, 1969

Chesapeake Technical Support Laboratory

Station	Sta. No.	Sample Time	Water Temp. °C	Total P mg/l PO_4	TKN mg/l N	NO_2 NO_3 NO_3-N mg/l	NH_3 N mg/l	Chloro-phyll a_o ug/l	Chloro-phyll a_a ug/l	DO mg/l	BOD mg/l	Coliform MPN 100ml	Fecal Coliform MPN 100ml
Indian Head Hwy. Bridge Rt. 210	P-0	1420	5.0	1.015	.241	.810	.168	1.50		10.78	12.50*	9,180	3,480
Farmington Lodge Pt. in Bay	P-4	1215	3.5	4.160	.279	1.300	1.780	27.00	24.75	11.07	10.24*	10,900	1,720
In Bay - Out from Marina	P-5	1230	3.0	2.210	1.480	.896	1.740	76.50	61.50	13.25	10.38*	80	20
Off Point - Below Marina in Channel	P-6	1240	3.0	3.250	1.370	.865	1.740	75.75	57.00	12.40	9.74*	< 20	< 20
Mid-Bay Off First Two Channel Markers	P-7	-	3.0	2.730	1.220	.876	1.720	40.50	38.25	13.03	8.21*	20	< 20
Confluence with Potomac Mid Channel at Markers	P-8	1305	3.0	3.050	1.700	1.010	1.840	9.00	09.75	13.95	8.92*	20	< 20
Off Monitor Sta. Buoy Potomac River	P-9	1300	4.0	3.510	1.300	.746	2.050	30.00	26.25	8.19	7.57*	< 20	< 20
Buoy 76 in Potomac River	P-10	1250	4.0	3.690	.749	.713	1.980	34.50	22.50	8.85	5.74*	20	< 20

*6-Day BOD

GLOSSARY

A = Cross-sectional area, $miles^2$

c = Concentration of the substance, parts per billion (ppb)

C_i = Mean dye concentration in "i" th segment, lb/cf

C_o = Peak concentration, (ppb)

d = Dye loss rate, constant (day^{-1})

D = Mass flow rate, (lbs/day)

E = Dispersion coefficient, square miles per day (smpd)-O'Connor's Method; Analogus to K, the longitudinal dispersion coefficient-Thomann's Method

E_i = Turbulent exchange factor for upstream boundary of the "i" th segment, (cf/day)

ε = A dimensionles proportionality factor used to estimate the concentration at the upper boundary of the "i" th segment

k = 1st order decay rate, per day

K = Longitudinal dispersion coefficient (smpd)

M = Mass of substance released

N = Rate of mass transfer across a boundary; (lb/sf/day)

P_i = Rate of dye added

Q_i = Net waterflow across the upstream boundary of the "i" th segment, cubic feet per day (cf/day)

r = Distance from point of release, miles

S = Sinks and sources

t = Time, days

U = Velocity of fresh water, cubic feet per second (cfs)

BIBLIOGRAPHY

1. Jaworski, N. A., Lear, D. W., Aalto, J. A., "A Technical Assessment of Current Water Quality Conditions and Factors Affecting Water Quality in the Upper Potomac Estuary," Technical Report No. 5, Federal Water Pollution Control Administration, Middle Atlantic Region, Charlottesville, Virginia, 1969

2. Hetling, L. J., O'Connell, R. L., "A Study of Tidal Dispersion in the Potomac River," CB-SRBP Technical Paper No. 7, Federal Water Pollution Control Administration, Region III, 1965

3. Hetling, L. J., "The Potomac Estuary Mathematical Model," Technical Report No. 7, Federal Water Pollution Control Administration, Middle Atlantic Region, Charlottesville, Virginia, 1969

4. Hetling, L. J., "Simulation of Chloride Concentrations in the Potomac Estuary," CB-SRBP Technical Paper No. 12, Federal Water Pollution Control Administration, Middle Atlantic Region, Charlottesville, Virginia, 1968

5. O'Connor, D. J., "Delaware Estuary Comprehensive Study," Technical Report No. 1, U. S. Department of Health, Education, and Welfare, Public Health Service, Division of Water Supply and Pollution Control, 1962

6. O'Connor, D. J., "Estuarine Distribution of Nonconservative Substances," Journal of the Sanitary Engineering Division, ASCE, No. SA1, pp. 24-42, February, 1965

7. Thomann, R. V., "Mathematical Model for Dissolved Oxygen," Journal of the Sanitary Engineering Division, ASCE, No. SA5, pp. 2-30, October, 1963

8. Aalto, J. A., Jaworski, N. A., "A Water Quality Study of the Piscataway Creek Watershed," Federal Water Pollution Control Administration, Middle Atlantic Region, Charlottesville, Virginia, August, 1968